Digitized by the Internet Archive
in 2023 with funding from
Kahle/Austin Foundation

https://archive.org/details/icsreferencelibr0000vari_z1g8

'10–

I. C. S.
REFERENCE LIBRARY

A SERIES OF TEXTBOOKS PREPARED FOR THE STUDENTS OF THE INTERNATIONAL CORRESPONDENCE SCHOOLS AND CONTAINING IN PERMANENT FORM THE INSTRUCTION PAPERS, EXAMINATION QUESTIONS, AND KEYS USED IN THEIR VARIOUS COURSES

1-122 m

ELECTRIC RAILWAYS
INTERIOR WIRING

4-17847

SCRANTON
INTERNATIONAL TEXTBOOK COMPANY
4

Copyright, 1901, 1904, by INTERNATIONAL TEXTBOOK COMPANY.

Entered at Stationers' Hall, London.

Electric Railways, Parts 1, 2, 3, and 4: Copyright, 1901, by INTERNATIONAL TEXTBOOK COMPANY. Entered at Stationers' Hall, London.

Electric Railways, Part 5: Copyright, 1900, 1901, by THE COLLIERY ENGINEER COMPANY. Copyright, 1901, by INTERNATIONAL TEXTBOOK COMPANY. Entered at Stationers' Hall, London.

Electric Railways, Part 6: Copyright, 1899, 1901, by THE COLLIERY ENGINEER COMPANY. Copyright, 1901, by INTERNATIONAL TEXTBOOK COMPANY. Entered at Stationers' Hall, London.

Interior Wiring: Copyright, 1901, by INTERNATIONAL TEXTBOOK COMPANY. Entered at Stationers' Hall, London.

All rights reserved.

PRINTED IN THE UNITED STATES

BURR PRINTING HOUSE
FRANKFORT AND JACOB STREETS
NEW YORK

287

2883

CONTENTS

ELECTRIC RAILWAYS.

(PART 1.)

INTRODUCTORY.

1. Electricity is now generally conceded to be the most economical agent for the transmission of power for the operation of street railways. It has shown itself superior to horses, compressed air, or cable, both as regards flexibility and cheapness of operation. Cable roads are advantageous in some very hilly localities, but for ordinary traffic even those cable roads already in use are being gradually converted into electric lines. Compressed air has been used in a few cases, notably in mining work, but for general purposes electricity now has the field practically to itself.

METHODS OF SUPPLYING CURRENT.

2. Several different methods may be used for supplying electrical energy to the cars, and the one to be used in any given case is generally fixed by local conditions. The methods that may be used for supplying current to the motors may be classed as follows:

a. By means of an overhead conductor or pair of conductors connected to the car by an under-running contact. This is known as the **overhead-trolley system.**

b. By means of underground conductors run in a conduit and connected with the car by means of a contact plow

For notice of copyright, see page immediately following the title page.

passing up through a slot. This is usually called the **open-conduit system,** or **slot system.**

c. By means of electromagnetic switching devices that make connection between the car and a conductor situated underground. This is often called the **electromagnetic system.** The conduit in which the conductor is run is, in this case, closed; hence, the name **closed-conduit system** is sometimes applied to this method of operation.

d. By means of a third rail run alongside of, or between, the car rails, contact being made with the third rail by means of a sliding shoe attached to the car. This is known as the **third-rail system.**

e. By means of storage batteries carried on the car. In this case no conductors between the power station and cars are necessary.

3. The overhead-trolley system is the method of operation used in the greatest number of cases, because it is the cheapest to install.

The slot system is used in a number of large cities where overhead wires are not allowed and where the traffic is heavy enough to warrant the expense. It is used, for example, in New York, Washington, Paris, etc., but it is altogether too expensive for the ordinary run of electric railroads.

The closed-conduit system has not yet come into commercial use to any extent. It is expensive to install and is comparatively complicated.

The third-rail method is extensively used for cross-country or suburban lines where the traffic is heavy and where a more substantial construction than the overhead trolley is necessary. It is also used for elevated roads, but is not permissible for surface roads in cities because of the liability of persons coming into contact with the third rail.

Cars operated by storage batteries have never been used very extensively, although they are used in special cases where overhead wires will not be permitted and where the traffic is not heavy enough to warrant the expense of

putting down a conduit system. Each car is provided with storage cells, arranged so that they may be easily replaced by fresh ones when they become discharged.

The above methods cover those that, at present, are available for the supply of electrical energy to the motors. We will at this point take up very briefly each of these methods in turn in order to see how the current is supplied in each case. The details by which the methods are carried out will be treated more fully later on, when the subjects of track and line construction are taken up.

4. Overhead-Trolley System.—The general arrangement of the overhead-trolley system is shown in Fig. 1. The positive terminal of the dynamo connects, through the switchboard, to the overhead-trolley wire. The negative terminal connects to the rail. The path of the current is indicated by the arrows. The current is carried to the moving car by means of the under-running trolley wheel, and all the cars on a given system are operated in parallel.

This arrangement, simple as it may seem, was not arrived at before considerable experimenting had been done. In the early electric roads two trolley wires were used, and the track was not employed as one side of the circuit. This scheme is still used in a few places, notably in Cincinnati. Also, on the first roads installed, the trolley wheel ran on top of the wire; but this method of collecting the current was soon superseded by the under-running trolley.

It should also be noted that the cars are operated in parallel. This is true of all systems of distribution where current is supplied to the cars from a central station. All street-railway systems are, therefore, operated at approximately constant potential, i. e., constant or nearly constant pressure is maintained between the trolley wire and the track by means of the dynamos in the station. Whenever connection is made from the trolley to the track through the motors, a current flows and the car is propelled. Each car is independent of the others and takes an amount of current proportional to the power required to drive it.

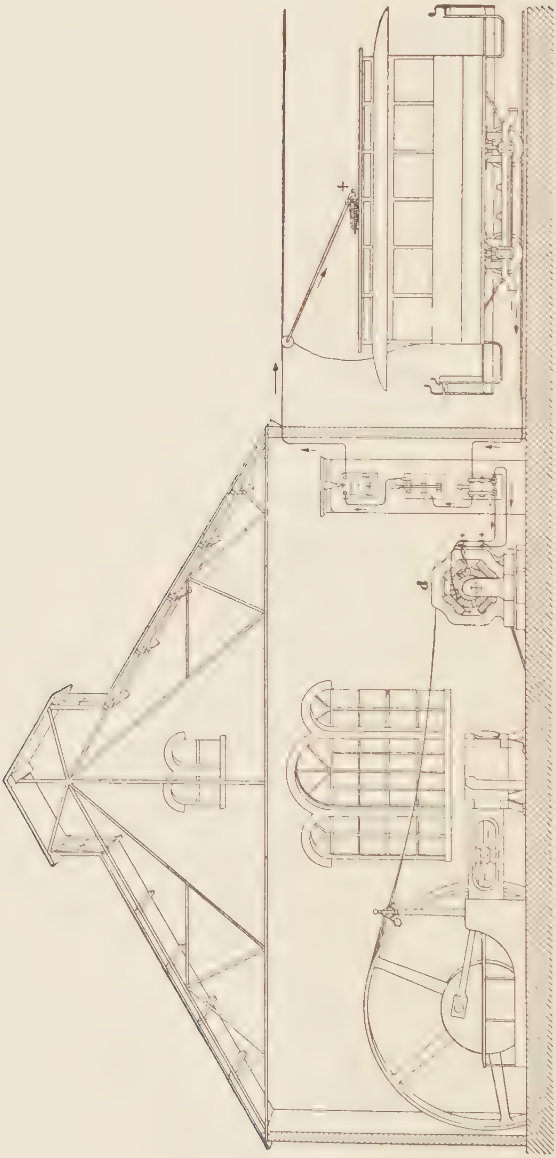


FIG. 1.

5. Schemes have been brought forward from time to time for operating street cars in series, but none of these have ever been put into everyday operation, and it is not worth while devoting space to them.

The arrangement shown in Fig. 1 may of course be modified. For example, except on very small roads, the trolley wire is not sufficiently large to carry the current necessary; so **feeders**, or heavy cables, are run to the station instead of carrying back the trolley wire itself. Also, return cables are sometimes used in connection with the track.

6. The Open-Conduit System.—The open-conduit system has not been put into very extensive use, because the expense of construction is very high compared to the overhead-trolley system. Where it has been installed, it has been a matter of compulsion, the city authorities refusing to allow the stringing of trolley wires and feeders above the surface. Two bare conductors are used, and these are held

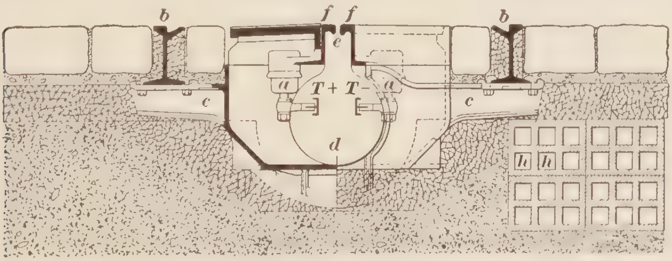


FIG. 2.

on insulating supports in the upper part of a channel or conduit, built in the roadway between the car rails, in the same way as a conduit for a cable road. In fact, in several instances the old cable conduit has been fitted up for use as a conduit for railway conductors.

The general method of construction, illustrated in Fig. 2, shows the style of conduit used by the Metropolitan Street Railway Company, New York. The rails are supported on cast-iron yokes in place of the ordinary ties, and the conduit extending between these yokes is made of concrete. Concrete is filled in around a sheet-iron form, which is

afterwards removed, thus leaving a continuous tube or duct of concrete between the yokes.

In Fig. 2, $T+$ and $T-$ are the conductor rails, which connect through feeders run in the underground ducts h, h. The track is not used for one side of the circuit, as in the overhead-trolley system. The **T**-shaped conductor rails are attached to insulators a, which are, in turn, suspended from the slot rails f. Handhole covers are provided at the insulators in order to give access to the insulators and conductor rails.

Fig. 3 shows an enlarged view of a portion of a yoke, showing the method of mounting the conductor rail. The feeders that supply the conductors are buried along the side of the track in terra-cotta or cement-lined tubes. To obviate the necessity of having to raise the paving, more tubes than are necessary to fill the requirements of the present service are put down, so that in the future, when it may be necessary to lay more feeders, there is a place ready for them. To facilitate the installation of new feeders or the repair of old ones, manholes are provided every 400 feet.

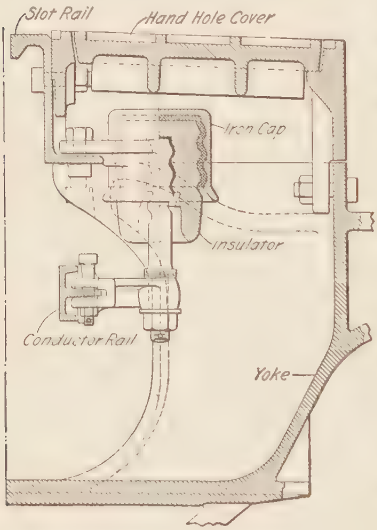


FIG. 3.

Mud accumulates in the main conduit very fast, and if not promptly removed gives trouble. At intervals of 200 feet there are manholes in the main conduit; at the bottom of the manhole is a 6-inch drain pipe leading to the sewer. The main conduit must be cleaned about once a month in the summer time, and perhaps oftener than this during the winter. By means of special scrapers, the mud is drawn into the manhole and is then lifted out and carted away.

7. The conductor rails are not continuous, but are divided into sections about a mile long, and each section is fed by its own feeder from the power house. There is no electrical connection between these feeders, so that the road is cut up into insulated sections, and trouble on one section is not so liable to interfere with the traffic on the others. Each feeder has its own switch and circuit-breaker. In case a ground occurs on one section, the circuit-breaker in the feeder that feeds that section flies out; the attendant in charge at the power house can tell exactly on what stretch of track the trouble is, and notifies the emergency crew to that effect, if it is necessary. Splitting the road into sections supplied by individual feeders has also the advantage that in case of a block on the road, the simultaneous efforts of all the motormen to start their cars will not cause heavy overloads in the power house, because the switchboard attendant has every section of the road under his control and can compel the cars to start up, one section at a time.

8. Fig. 4 shows the style of plow used by the Metropolitan Company. The plow is provided with two iron contact shoes *s*, *s* that press sidewise against the conductor rails *a*, *a* under the action of the flat springs *b*, *b'*. Connection is made to the car by means of cables *c*, *c'*, which connect to the shoes by means of flat insulated strips passing through the flat part of the plow and connecting to the shoes by means of flexible cables *d*. The plow passes between the slot rails *e*, *e* and is securely fastened to a crosshead underneath the car. This crosshead is mounted so that it can move from one side of the car to the

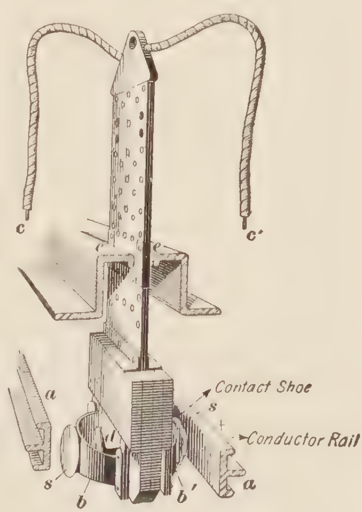


FIG. 4.

other, in order that the plow can change its position relative to the car when necessary.

9. As stated above, the open-conduit construction is very expensive. It is necessary that the yokes be well designed to resist the pressure of the earth (which is packed down by the heavy traffic) and the very heavy pressure in cold climates, due to the freezing of the soil, with its accompanying expansion. Wrought iron, steel, and cast iron have been used for this purpose, the latter, perhaps, being the most used. When yokes of light weight are put in, trouble is often occasioned by breakage. The conduit may be lined with steel plates or it may be constructed on the sides of concrete alone; in some cases the metal yokes have been replaced by concrete, but the best practice is to use heavy castings ranging in weight from 200 to 400 pounds or more, according to the depth of the conduit and the character of the wagon traffic expected.

10. Electromagnetic System.—In this system the regular rails constitute one side of the circuit, and the other side, by means of which the circuit through the car is completed, consists of an insulated third rail split into a number of short sections. These rail sections are supplied with current by successively connecting them to a line conductor run alongside the track.

Fig. 5 will give an idea as to the method of operation. G is the dynamo in the power house. The negative pole of G is connected to the rails t, t_1, as in the ordinary overhead-trolley system. The main conductor m, which is well insulated, is connected to the + side of the generator, and connection is made from it to the sectional rail $r\ r\ r$ through switches s, s. The switch is enclosed in a rectangular box located between the middle rail and one of the track rails and is provided with a non-magnetic cover hermetically sealed to prevent water from entering. Directly under this cover and connected to the switch lever are two armatures that are alternately attracted by magnets on the car, one at

the front and the other at the rear end, so that any section has current in it only so long as the car is passing over it. For collecting the current a sliding shoe is used.

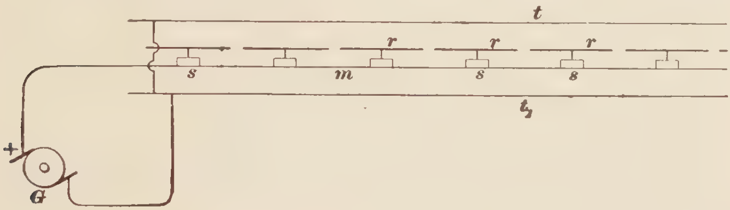


FIG. 5.

A number of other electromagnetic systems have been invented, but so far they have not been adopted very extensively. They have some good points, but these are outweighed considerably by the number of automatic switching arrangements necessary.

11. Third-Rail System.—It is common to hear the third-rail system spoken of as being something comparatively new in the electric-railway line. As a matter of fact, it was one of the very earliest methods used for supplying current to electric cars. One of the first electric roads put into practical operation was at Portrush, Ireland, and was operated on the third-rail system. Of late years the third rail is coming into favor, especially for heavy work. For interurban and elevated-railroad work something more substantial than a trolley wire is required, because the speeds are high and the current to be handled is large. In this system a third rail is mounted, usually at one side of the track, and contact is made with it by means of a sliding shoe carried on the car. The rail is mounted on special insulators and is generally raised somewhat above the other rails. The regular track rails constitute the return circuit. At grade crossings the third rail is omitted, as the momentum of the car is sufficient to carry it over. Of course, the third rail can only be used where there will be no liability of persons coming into contact with it, but for the class of

work mentioned above it gives very satisfactory service and its use is rapidly extending. For example, elevated trains in New York, Chicago, and Boston are operated by means of the third rail.

12. Fig. 6 shows a third-rail construction used on the Nantasket Beach and East Weymouth Road. The third rail *r* is, in this case, of special shape, though ordinary **T** rails are often used. The rail shown is made in 30-foot lengths and weighs 93 pounds to the yard. It is shown supported on posts *a*, which are treated with creosote.

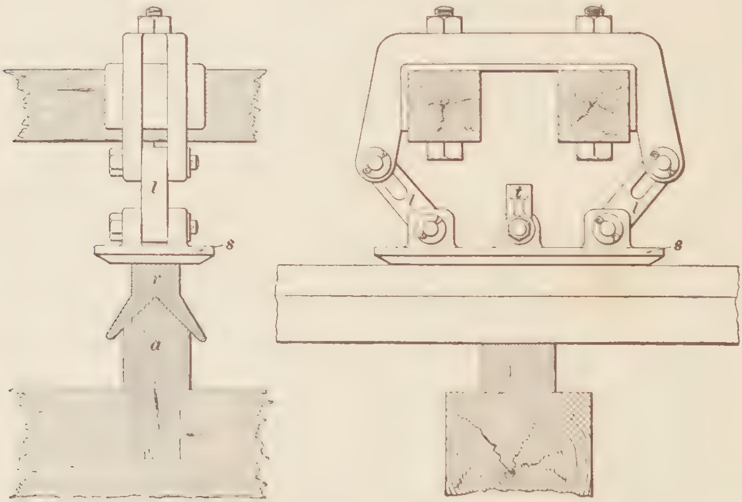


FIG. 6.

Electrical continuity between the rails is secured by fastening them together by copper **bonds.** In the later styles of third-rail equipment, which will be described more fully when track construction is taken up, porcelain or granite insulators are used for supporting the rail.

The shoe *s*, Fig. 6, slides on the rail and conveys the current to the car by means of a cable fastened to the terminal *t*. The slotted links *l* allow the shoe to play vertically, so as to follow inequalities in the track. There are two contact shoes and frames to each car on this particular

road and they are placed 33 feet apart, so that at road crossings the third rail may be omitted and the momentum of the moving car depended on to carry it over. When the width of the road is less than 33 feet, there is no break.

CURRENT SUPPLY.

13. Direct Current vs. Alternating.—Electric street cars are operated almost wholly by means of direct current. This means that the current actually supplied to the motors is direct, although the current generated in the central power station may be alternating. The reason for this is that the alternating-current motor has not as yet proved as reliable for this class of work as has the direct-current motor. It must be remembered, however, that alternating-current induction motors have been making rapid advances, and some railroads in Europe are at present operated by them. It is not at all improbable that in the future alternating-current motors will be more used on electric cars, but the practice so far in the United States has been to convert the alternating current into direct current by means of rotary transformers and to use direct-current motors on the cars rather than to supply the alternating current directly to induction motors.

Induction motors, if properly designed, can be made to give a strong starting effort, which is one thing very necessary in a street-car motor. Three-phase motors have been used on what few roads have been equipped with alternating-current apparatus. The three-phase system requires three wires, and as the track answers for one of them, two overhead wires are needed. This complicates the overhead construction and has been brought forward as one argument against alternating-current motors for street-railway work.

While alternating-current motors themselves have not made very great headway in street-railway work, the use of alternating current at high pressure as a means of transmitting the power has come into much favor, because it

allows the cars to be operated from a central station situated some distance from the point where the power is used.

14. Voltage.—The pressure at which current is supplied to the cars is limited by considerations of safety. It would, of course, be desirable to use a high pressure, because this would mean a small current for a given amount of power, and small feeders would be sufficient. However, a pressure is soon reached where it would be decidedly dangerous to life, and for this reason the working voltage on street railways has been fixed at about 500 volts. On some suburban lines the pressure runs over 600 volts, and again in other places it will be found much lower than 500 volts, on account of an excessive drop in the line. Railway motors and other apparatus are designed for 500 volts, and the pressure on the line should be maintained at or near this point. Low voltage requires a correspondingly large current to supply enough power to operate the cars at the required speed; hence, if the pressure is lower than normal, heating of the motors is liable to result.

THE POWER HOUSE.

15. In considering electric railways in detail, it will be convenient to divide the subject into three parts, as follows: (*a*) the *power house;* (*b*) the *line and track;* (*c*) the *car equipment.*

We will take these up in their order, beginning with the power house and the apparatus with which it should be equipped.

LOCATION OF POWER HOUSE.

16. General Considerations.—The **power house,** or **power station,** as the name implies, is the place or source of supply of power for running the cars, and it should be situated as near the center of the system as possible. By

the center of the system is meant the center of the load or traffic. In other words, since wires must be used to convey the power from the power house out to the point where it is to be used, a part of the power generated will be lost in these wires, because they always have some resistance. If the line wires are not of sufficient size, they will cause a loss of power that will make itself very strongly felt in its effect on the speed that the cars make and also upon the amount of heat that the motors develop. Laying other things aside for the present, the amount of loss in one of these supply wires depends on its length and on the amount of current that it may be called on to carry. Hence, it follows that the center of the load may not be the geographical center of the system. As a matter of fact, these two centers very seldom fall in the same place. The true load center is located in the same way that the center of gravity of any system of bodies is located. The geographical center, as we have called it, depends on the number of miles of track and how these are disposed; the other depends on how the load is distributed.

In Fig. 7, *A B* represents 10 miles of track free from grades and sharp curves, and on this track a certain number of cars *1*, *2*, *3*, *4*, etc., of about the same weight and equipped with motors of the same size, run at regular intervals. It is easily seen that the geographical center, or center of mileage, is in this case located at *P*, a point midway between the two ends, so that there are 5 miles of track on each side of it. It can also be shown that the load center in this particular case is also at *P*; for, suppose that all the cars, except the two on the extreme ends, are running at full speed. Since the track is level and the cars and motors are alike, they will all take about the same power, and since the loads are evenly distributed throughout the length of track, they can be represented by circles of the same size, as shown in Fig. 7. Here, there are seven loads on each side of the center line passing through *P*, and if each circle is supposed to represent a weight of a certain number of pounds, and the center of gravity of the system

of weights is to be determined, it will be found to fall on the center line $c\,l$. So also, if all cars, except the two end ones, are supposed to stand still or to coast along with the power off, and the two end ones start at the same time, the same load will be drawn to both ends of the line, and point P will still be the center of load and will therefore mark the spot where the power house should stand.

It is not intended to convey the idea that the load, even on such a simple layout, will always be as evenly distributed as has been supposed in this ideal case, for, as a matter of fact, such a condition will be the exception rather than the rule. Suppose A to be in the outskirts of a large city and

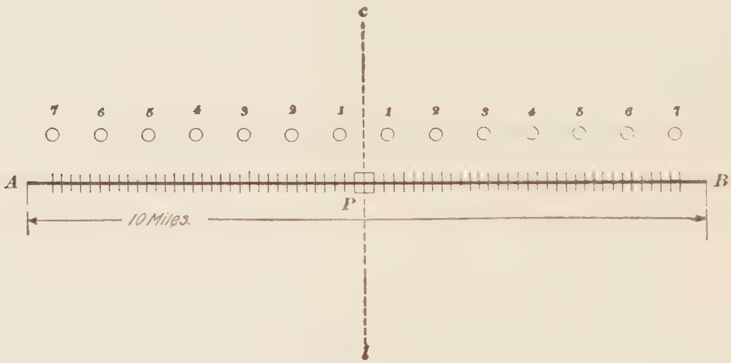


FIG. 7.

suppose B to be down-town, where the people must all go to business; then, in the mornings and evenings, when the crowd is going to and coming from work, the load leans a little towards the B end of the line, but during the rest of the day it is uniformly distributed. To alter conditions, suppose that from the middle of the line to B there is an up grade. It is easily seen that those cars that are ascending the grade will be called on to do more work than those on the level and on the down grade, so that the final effect will be to shift the ideal site for the station towards B. In this case, the mileage center remains the same, but the load center is changed.

17. Influence of Future Extensions.—In locating the site for the power house, future extension and increase in traffic incidental to the development of outlying districts should be borne in mind and the site selected accordingly. Long experience and computation have proved that it is not profitable, with the ordinary direct-current, 500-volt transmission, to operate cars at points more than 7 miles from the house, because, in order to keep the line loss down to a reasonable amount, the feeders must be so large that their cost becomes excessive.

Suppose, for example, as shown in Fig. 8, that the full-line section *A B* represents the stretch of track put down at the first building of the road and that, in accordance with the demand at that time, the power house was put at *P*, the center of load for *A B*, which is supposed to be level.

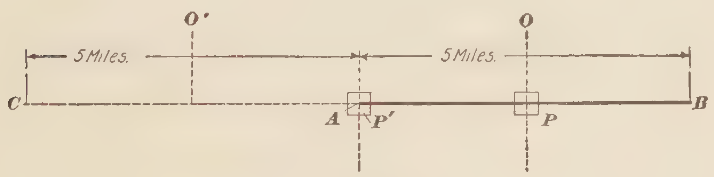


FIG. 8.

Now, suppose that the road has been extended out to a point *C*, so that $A B = A C$. If we further assume that the district through which *A C* runs becomes built up, it will be only a matter of time when the travel density will be as great on the new stretch of track as it is on the old, in which case, assuming the different load units to be fairly evenly distributed throughout the distance *B C*, the proper place for the power house would be at point *P'*, midway between *B* and *C*, the two ends of the road.

For, suppose $B C = 10$ miles; then will $A C = A B = 5$ miles, and $PA = PB = 2\frac{1}{2}$ miles. As long as *A B* constituted this whole road, the power house situated at *P* was at the center of an evenly distributed load, and the same loss of power would attend the transmission of a given amount of power to one end of the line as to the other.

As soon, however, as the extension $A\ C$ is started, it is not a difficult matter to see that a power house at P would be $2\frac{1}{2}$ miles from the B end of the road and $C\ A + A\ P$ or $7\frac{1}{2}$ miles from the C end of the road. Under such a condition, should all the cars, through trouble of some sort, become congested at the far end of the line, the line loss incidental to the great distance and to the large current caused by trying to start all the cars at once would seriously delay getting the cars on their time again. By moving the station to A, matters will be righted.

If the station were put at A in the first place, it would, of course, be at one end of the line as long as $A\ B$ were the whole road, and would not therefore be at the center of load; but if the extension $A\ C$ is only a matter of time, it will be far the better plan to put up with the line loss due to want of balance on the shorter line, locate the station at A, and be prepared to get the best results when the extension is in operation and the number of cars, therefore, greater.

18. If, in deciding the best location for the power house, it were only a matter of fixing the probable center of load, the problem would be a comparatively easy one. In many cases, as we shall see later, the problem is an easy one; but in other cases it is made very hard and almost impossible to solve, except approximately, by the fact that several other considerations have a great influence on the location. The prospective center of the load might be located under conditions that point with absolute certainty, from a purely electrical point of view, to the desirability of a certain place as a site for the power house; at the same time, this place might prove to be so situated that every pound of coal to be burned under the boilers would have to be hauled to the power house. Again, the center of load might fall at a place where it would be difficult to get water for the boilers and the condensers; such a place would, of course, be out of the question. Finally, the question of land comes in. It would be a very poor move to build a power house

in a part of a city where a city building would probably pay as good dividends as many well-managed roads. In such a case, then, there must be a careful comparison made between what an improved building on the proposed site would pay and what the annual power loss would be as a result of selecting some other power-house site electrically not as good as the center of load. It can be seen, then, that the final selection of a site for the power house must, in some cases, be a compromise between conflicting conditions. Load conditions will point to one site; good, cheap water and plenty of it will point to another site; the coal bunkers should be arranged so that the coal may be passed directly to them from the boat, or at least from a coal car that can be run alongside of them by means of a siding or a spur from the main line. Very often a point can be selected to fulfil all these conditions; but just as often it is necessary to select a compromise that will be fair to all of them. It is not hard to see, therefore, that the proper solution of the problem may require a great deal of study, work, and experience.

DETERMINING THE LOAD CENTER.

19. In illustrating the method used for obtaining the load center, we do not intend to deal with roads that require the equalization of the advantages incidental to the above limiting conditions. Such a consideration involves details that are beyond the scope of this Course; also, the conditions vary so widely that it is almost impossible to lay down any rules that can be applied with safety in particular cases. We shall assume, therefore, that in all cases the layout of the road is along the lines shown in the diagrams, and that, as there are no limitations imposed by coal, water, and property requirements, the selection of a site for the power house resolves itself to the determination of the load center. To find the load center, the engineer must have a knowledge of the traversed district. With this knowledge

in hand, the problem can be treated graphically, and it amounts to the same thing as finding the center of gravity of a system of bodies. As an example, in Fig. 9, W and W' are two bodies whose centers are 11 feet apart, and each of which, for example, weighs 20 pounds. Since, in this case,

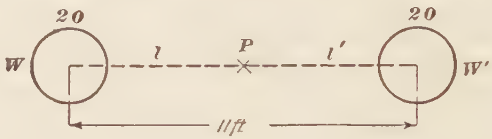


FIG. 9.

the two weights are equal, the distance of their centers from the center of gravity P must also be equal, in order that $W \times l$ shall equal $W' \times l'$. The center of gravity is, therefore, midway between the two bodies, and the system, as a unit, acts the same as if a weight of 40 pounds were fixed at P.

20. Finding the center of gravity of W and W', in Fig. 9, amounts to about the same thing as finding the center of load or the location of the power house in Figs. 7 and 8. Take Fig. 8, for example. The load is supposed to be uniform over the two sections $A\,B$ and $A\,C$. Let $A\,B = A\,C = 5$ miles. Suppose that there are 10 cars on each section and that each car averages a load of 20 horsepower. Each section will, then, carry a load of 200 horsepower, and all this load can, in each case, be supposed to be concentrated at points O and O' in the center of the respective sections. These centers, will, therefore, be $\frac{1}{2}\,A\,B + \frac{1}{2}\,A\,C$ miles apart; that is, 5 miles apart. The two loads of 200 horsepower concentrated at points O and O' in Fig. 8 correspond to the two weights of 20 pounds in Fig. 9, and if we treat the 200 horsepower as weights and find their center of gravity, that center of gravity will be the center of load or the correct location for the power house. Since the two loads or weights are equal, the center of gravity or load must, as in Fig. 8, be at point A, midway between O and O'

21. Take another case. Suppose that there are three weights (Fig. 10): $W = 40$ pounds; $W' = 50$ pounds; and $W'' = 10$ pounds; further, suppose that the distance from W to W' is 6 miles; from W to W'', 7 miles; and from W' to W'', 4 miles. Where is the center of gravity situated? The way to ascertain this is to first find the center of gravity between any two of the weights, and then, supposing the sum of the two weights to be situated at this point, to find the center of gravity between this and the third weight. Let us first find the center of gravity between weights $W = 40$ and $W'' = 10$, where the distance

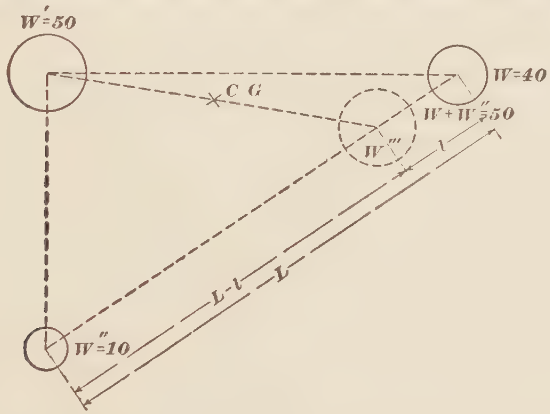


FIG. 10.

between centers is 7 miles. This distance of 7 miles must be divided into 2 parts, such that $W \times l = W'' \times l''$, where l and l'' are the distances of W and W'', respectively, from the center of gravity for these two bodies. To solve the problem graphically, lay out the plan to scale on paper; that is, represent the 7 miles by 7 inches, and so on, and let a difference in the sizes of the circles represent the difference in weights, as shown in the diagram. Call L the distance from W to W'', and let the distance from W to the center of gravity, to be found, be represented by l; then the distance of W'' from the center of gravity will be represented by the difference, or $L - l$; and since $W \times l = W'' \times (L - l)$, we have $Wl = W'' L - W'' l$, or $W'' L$

$= W' l + W'' l$, and $l = \frac{W'' L}{W' + W''}$. Substituting for the weights and for L the numerical values given, we have $l = \frac{10 \times 7}{50}$ $= 1\frac{2}{5}$ miles, or inches on the paper, as the distance of the weight W from the required center of gravity. Since the total distance $L = 7$, the distance from the center of gravity to the center of W'' must be $L - l$, or $5\frac{3}{5}$ miles. Now take a pair of dividers and a scale and on the line joining the centers of W and W'' locate a point that is $1\frac{2}{5}$ inches from the center of W; this is the center of gravity sought, and it will be $5\frac{3}{5}$ inches from the center of W''.

It is now in order to find the center of gravity between the large dotted circle, representing the combined weights (50 pounds) of W and W'', situated at their center of gravity, and W', which is also 50 pounds. Call the dotted circle W'''; since the weights W''' and W' are the same, it is evident that their center of gravity is midway between them on the line joining their centers, so that it is only necessary to take a pair of dividers and bisect this line in order to find the center of gravity of W' and W''', and hence of the whole system.

22. Conclusion.—The general rule, then, for locating the center of load or the best position for the power house is as follows: Divide the line of the proposed road into several sections; with a knowledge of the service to be rendered on the road, assign a certain load in horsepower, kilowatts, or amperes to each section. Lay out, to scale, a plan of the road on paper. Suppose that the load assigned to each section is concentrated at its middle point; there will then be as many of these points as there are sections, and each point will bear a number designating the load on the section of which that point is the center. The numbers can be considered as representing weights and the center of gravity of all of them determined as shown in the preceding articles. The center of gravity so found will be the load center that marks the best location for the power house.

STATION EQUIPMENT.

ENGINES AND BOILERS.

23. The type of engine most suitable for use in a railway power station depends on the size of road, that is, on the number of cars in regular operation. The closest speed regulation under widely varying loads is obtained with high-speed, automatic cut-off engines, and this class is, therefore, particularly suitable for very small roads. It is easily seen that such a road furnishes extremes of load at very short intervals of time, for if there is only one car in service, the station load, except for the friction losses, field exciting currents, and a few lamps, is zero when that one car is at rest or on a down grade, and is at a maximum when the car is starting on a steep up grade. When a second car is added to the service, the chances are less that such extreme variations will occur, and the more cars that there are in service, the nearer will the load approach something like a constant normal value. The more cars that there are, the less probable is it that all of them will be taking no power at the same time, so that the station is under a certain amount of load all the time. It does not matter how large the output of the station may be, the load fluctuations will be sudden and violent; but still, if the station is large, a given variation in the load is a smaller percentage of the total load and is, therefore, not felt as much on the generating and regulating devices. On stations of any size, the load, as a rule, has several high values during a day of 24 hours. The two greatest values occur in the morning, when the people are going to work, and at night, when they are coming from work. Around noon and on towards 2 o'clock, when the shoppers begin to move, the load is again above normal. The time of occurrence of maximum and minimum loads depends a great deal on local conditions; it is different on different roads, and sometimes on the same road it differs from day to day.

24. As stated above, high-speed, automatic cut-off engines are suitable for small roads where the load fluctuates rapidly. Mine-haulage plants, for example, are usually of this class. On most roads, however, it has become the practice to use slow-speed engines of the Corliss type, especially when the load is moderately large. In moderate sized stations, where space is not scarce, belted dynamos are used. These machines are usually driven directly from the flywheel of the engine. The station is made up of a number of units, each consisting of an engine belted to its dynamo. Countershafts are not now used to any extent in railway plants, the tendency being rather to split the station into a number of distinct units. When the units are very large, and also in case space is limited, direct-connected engines and dynamos are to be preferred. In some of the largest stations, vertical Corliss engines are used, and these are generally of the compound or triple-expansion type. The first cost of a direct-connected dynamo is greater than a belted one for the same output, but the saving in space and absence of belts go far to compensate for this and account for the rapidly increasing use of direct-connected units. When this class of machinery was first used, trouble was caused in some instances by magnetic leakage. This magnetized the shaft and bearings in such a way as to cause a lateral thrust on the shaft and give rise to hot bearings. In the later styles of machines, the design in this respect has been so improved that this trouble has been done away with to a large extent.

25. On most large direct-connected railway sets using slow-speed engines, a heavy flywheel is provided. The fact that the steam and electric units are rigidly connected and that the dynamo armature has great inertia complicate the conditions in case of an excessive overload due to a short circuit or other abnormal condition on the line, because, in the case of a short circuit, there is nothing to finally relieve the strain on the dynamo should the circuit-breaker fail to open the circuit at once. With a belted unit, an excessive load causes the belt to slip—a clutch will act in the same

way—so that a belt or clutch acts as a kind of mechanical safety device to cushion the shock that the dynamo gets in case of a sudden overload. On the whole, however, everything is in favor of the direct connection, due precautions being taken to see that the circuit-breaker is set at a safe load and that it is in a condition to work at the load for which it is set. Generally speaking, very heavy flywheels should be used on engines for running street railways. The whole engine construction must be of a very substantial character, because it must be remembered that the load is much more liable to severe fluctuations than with electric lighting or ordinary power transmission work.

26. Size of Engines.—The size of engines and dynamos for different station units will, of course, depend largely on the total output of the plant. In general, it is not a good plan to have a large number of small units, but on the other hand, it is not economical to have only one or two large units, because under such circumstances, even if only one of these units were operated, it would be run on a load much below its capacity, and hence would operate at a low efficiency. The units should be arranged so that they may be kept loaded up to nearly their capacity. In most of the recent plants the units are of the same size and type, because a small stock of repair parts is then sufficient for the station. It is always an advantage to have the machinery in a station uniform, even if it is necessary to sacrifice a few advantages in other directions to attain this end.

27. Steam Piping.—What has been said with regard to steam piping for electric plants in general applies also to street-railway power houses. In some cases, duplicate steam piping is used to avoid shut-downs in case a break occurs, but in some of the largest and most modern power stations, duplicate piping is not used. The single piping is installed in a very substantial manner and with a large margin of safety, so that the chances of a breakdown in the piping system are very small. Duplicate piping is complicated and expensive, and for this reason there appears to be a tendency

to revert to the single piping and to install this in such a way that it will be able to meet all demands made on it.

28. Condensers.—The engines should, when possible, be run in connection with condensers. These condense the exhaust steam, instead of allowing it to exhaust into the air, and thereby create a partial vacuum behind the piston of the engine. This increases the effective pressure on the piston and results in a saving in fuel. Jet condensers are most commonly used in power plants. In this type the exhaust steam is condensed by being brought into contact with a jet of cold water. This of course heats the water, and if provision is not made for a fresh supply of cold water, the warm water must be cooled before it can be used over again. The warm water is pumped out by means of the air pump, which also carries out any air that may be mixed with the water.

This air pump, in large stations, is usually independently driven by an engine of its own. For smaller stations, it is generally arranged like a direct-acting steam pump, or else it is operated from the steam engine itself. In some instances, the air pumps and boiler-feed pumps are driven by electric motors.

29. Cooling Towers.—In many places it is not possible to get sufficient water to operate condensers without going to great expense. This is usually the case where the plant cannot be situated on a water front and where all the water used must be bought. Where the water supply is limited, **cooling towers** are used to cool the condenser water and enable it to be used over again. These are made in a number of different ways, but in most cases the water is cooled by allowing it to drop from the top of a tower in a thin sheet so that it will be exposed to the air. Sometimes the water is allowed to fall through a current of air set up by fans; in other cases, requiring a longer tower than the former, no artificial draft is used. In either case, the comparatively rapid evaporation of the water results in its being cooled enough so that it can be used over again.

30. Boilers.—The boilers used in railway plants are generally either of the return-tubular or water-tube type. In the former, the hot gases pass through flues or tubes surrounded by water, while in the latter the water is in tubes and the gases pass around them. The ordinary return-tubular boiler is low in first cost, is easy to keep in repair, and has given excellent service in many places. The water-tube type is, however, very largely used, because of its safety and because it can make steam very rapidly if occasion demands it. Both types of boiler have their good and bad points, and both are extensively used. Where space is scarce, vertical boilers may be used to advantage.

31. Fuel Economizers.—In places where coal is comparatively expensive fuel economizers are used. These are intended to heat the feedwater before it passes into the boilers by making use of the heat contained in the hot gases which would otherwise pass up the stack. The feedwater is circulated through a large number of tubes, which are so arranged that the hot furnace gases pass around them on their way from the boilers to the stack. By this means, the feedwater may be heated to a temperature much higher than when an ordinary exhaust steam heater is used.

32. Conveyers.—For large stations, coal and ash conveyers should be provided. The coal conveyer is usually arranged to take coal directly from the car or barge and carry it to the coal bunkers above the boilers. The ash conveyer runs along under the ash-pits, so that, as the ashes are dumped down, they are carried out. In small plants, conveyers are not, as a rule, provided, at least not on an elaborate scale, because the amount of coal and ashes to be handled is comparatively small. In large stations, mechanical stokers are used for firing the boilers.

33. Example of Station.—Fig. 11 shows a cross-section of the power station of the South Side Elevated Railway Company, of Chicago, and will serve as a typical example of a modern power house of comparatively large capacity. The station, like nearly all power houses, consists of two large

FIG. 11

rooms—the engine room *A* and the boiler room *B*—separated by a brick fire-wall *C*. Each of the engines *D* is of the cross-compound Corliss type and is coupled directly to its dynamo *E*. These engines are especially heavy and are rated at 1,200 horsepower each; they can, however, develop 2,000 horsepower if necessary. The generators *E* are of 800 kilowatts capacity and have 12 poles. They also will stand a heavy overload without damage. The exhaust steam from the engines passes to an independently driven jet condenser *F*, and the condensing water is cooled by means of a cooling tower placed outside the building. The cooling tower is divided into sections, and each section is provided with fans driven by the motors *G*, which are inside the building. If necessary, the engines may be allowed to exhaust into the air through *K*. The boilers *L* are of the water-tube type and are fed by chain-grate stokers *M*. Coal is supplied to the boilers from the bunkers *N* through the chutes *O*. The bunkers have a storage capacity of 1,000 tons, and are filled by means of the conveyer *P*, which carries a continuous chain of buckets and passes up the side of the plant, across over the bunkers, along under the ash-pits, and up the other side of the plant, thus forming a continuous chain. The coal is delivered to this conveyer by a second conveyer *R*, which takes it from the car. A fuel economizer *T* is used, so that the hot gases on their way to the stack *X* may be used to heat the feedwater. All the steam pipes from the boilers run to the main pipe *b*, from which run the steam pipes *c* to the different engines. The dynamo room is provided with an overhead electric traveling crane *Y*, to be used in placing or repairing the engines and dynamos.

ELECTRICAL EQUIPMENT OF STATION.

34. The electrical equipment of a power house may be conveniently divided into two parts: the part that generates the power and the part that is used to control its distribution to the point where it is used. The first part includes

the **dynamos,** or **generators,** as the dynamos are commonly termed when used for railway work. The second part includes the **switchboard,** with all its devices for controlling and measuring the current sent out on the line.

DYNAMOS FOR RAILWAY WORK.

35. The dynamos used for railway work are in general the same as those used for lighting or power distribution.

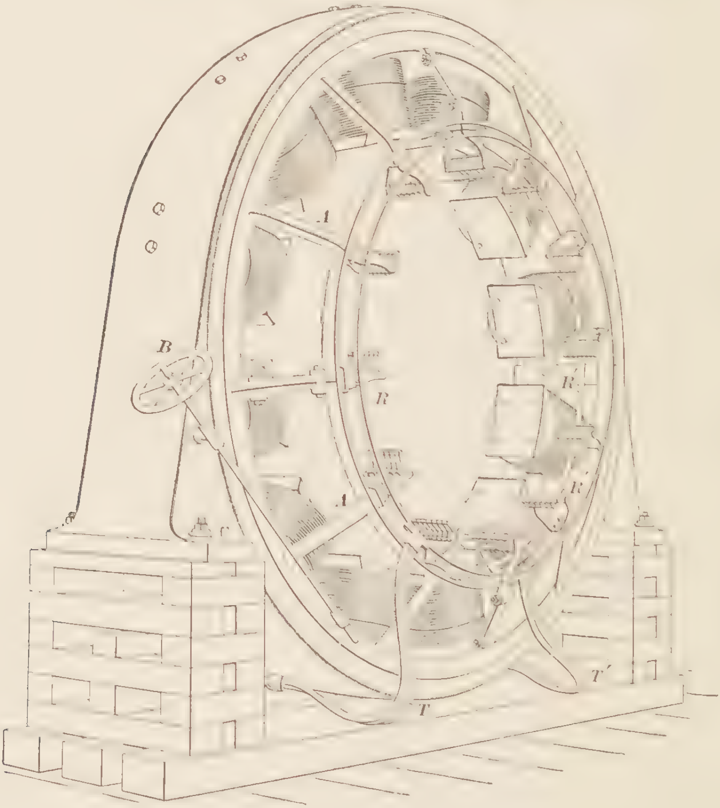


FIG. 12.

They should be exceptionally well built, so as to withstand the sudden strains thrown on them, and should be capable

of handling a considerable overload for short periods without excessive sparking or heating. Whether direct- or alternating-current generators are used will depend on the system of distribution adopted. When the power must be carried for long distances, the best plan is to install high-pressure alternating-current generators to supply current to substations located at various points on the system. In these substations the alternating current is changed to direct current by passing it through rotary converters.

In the great majority of cases, however, direct-current generators are used, and these supply current at a pressure of from 500 to 600 volts directly to the feeding system.

36. Direct-Current Generators.—These machines may be either direct-connected or belt-driven. The former type is now installed in most new stations, especially where the units are fairly large. Fig. 12 shows the field frame, with the field coils in place, for a typical 650-kilowatt direct-connected generator. Compound-wound dynamos are used almost exclusively for railway work, and the reasons for their use will be seen later. Each of the field spools is provided with two windings, a series and a shunt, as indicated in the figure. The brush holders, of which there are as many sets as there are poles, are carried by the frame *A A*, which is fitted into the field casting so that it may be revolved through a small arc by turning the wheel *B*, thus allowing the brushes to be adjusted to the point on the commutator that gives the least amount of sparking. Alternate sets of brushes connect to the rings *R*, *R'*, and to these rings the main armature cables *T*, *T'* are attached.

37. Fig. 13 (*a*) and (*b*) gives two views of a typical armature for a direct-driven railway generator. It will be noticed that the construction is very substantial and that the commutator *A* is of ample proportions. The conductors on the armature are in the shape of rectangular copper bars, which are sunk into slots in the periphery of the iron core. The ends of these bars, seen projecting at *a*, *a* on the commutator end, are connected to the commutator bars by the

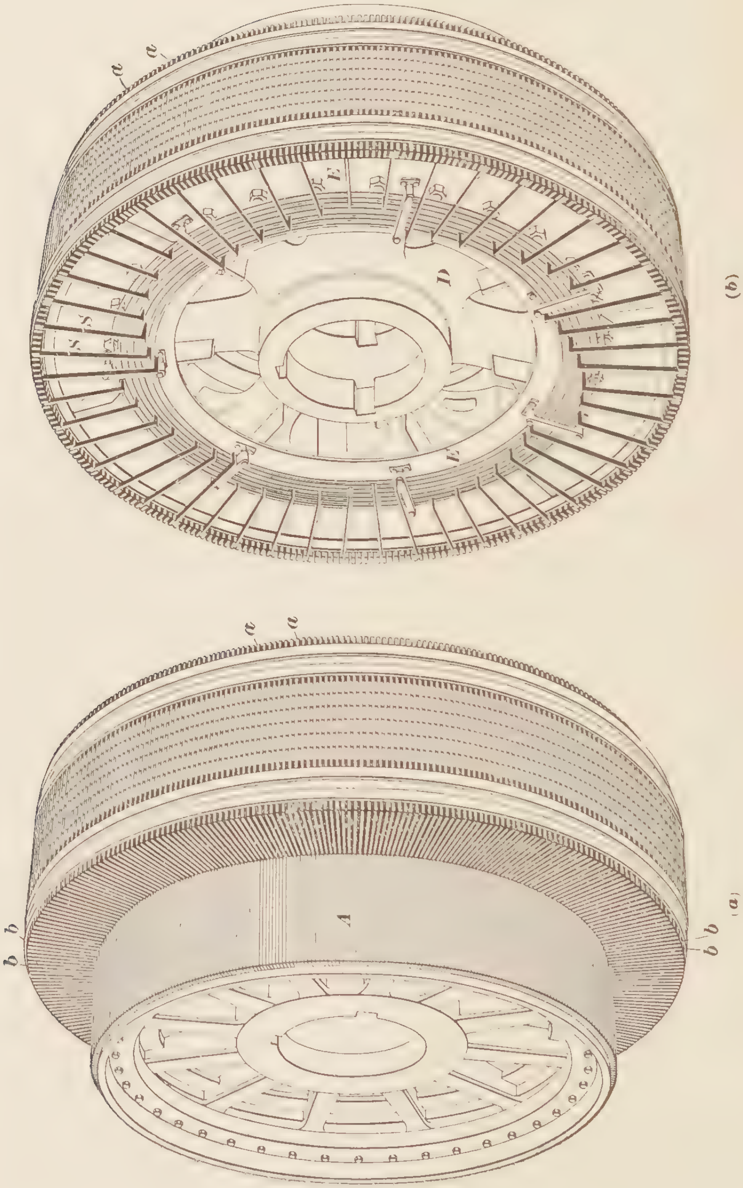


FIG. 18.

strips *b*, *b*. The laminated iron core on which the conductors are carried is mounted on the heavy spider *D*, which is keyed to the engine shaft. In these large multipolar armatures there are a number of paths in parallel; i. e., when the current enters at one side, it has the choice of several parallel paths through the armature. If the E. M. F.'s generated in these armature sections, as they might be called, were all exactly equal, the currents flowing in the different parts of the armature would also be equal. It is very difficult to have the magnetic field exactly equal all around the armature, because some of the poles may be slightly closer to the armature than are others, due to wear in the bearings or other causes. This causes the E. M. F.'s in some parts of the armature to overbalance those in other parts, giving rise to local currents that may cause the armature to heat considerably.

In order to balance the currents in the various parts of the armature, **equalizing rings**, shown at *E*, *E*, Fig. 13 (*b*), are sometimes used. These rings, to some extent, are similar to the equalizing connection used between dynamos running in parallel. They are mounted on the back of the armature and connect points in the winding that are normally at equal potential. If one section becomes overloaded, current flows through the equalizing rings to the other sections and the load is thus equalized. All armatures are not provided with these rings, and if the armature is correctly centered in the field, it works very well without them. The winding of the armature is the same in either case, the rings being simply connected by pieces *S*, *S* to the projecting ends of the bars at the back.

38. Fig. 14 shows a Westinghouse six-pole street-railway generator arranged for belt driving. The smaller units are, as a rule, belt-connected, and this is especially the case where there are no particular restrictions in regard to floor space. The dynamo shown in Fig. 14 has a substantial bearing on both sides of the pulley, so that there is none of the hang-over effect that is to be found on some generators

of the belted type. It is true that a belted generator is not as efficient commercially as a direct-connected generator of the same type and output, but for units up to 300 horsepower the difference can as a rule be neglected. The amount of power lost in friction on a belted generator depends to a great extent on the judgment of the man that

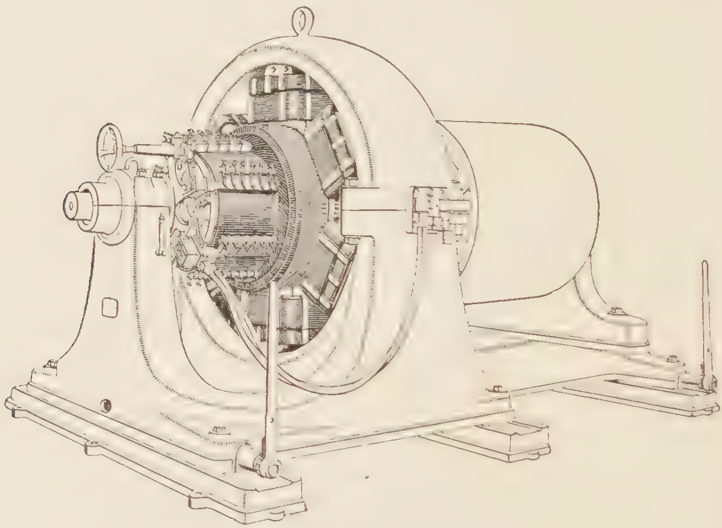


FIG. 14.

sets up the machine. If there is not room in the engine room to set the dynamo far enough from the engine, so that there shall be a slight sag in the tight side of the belt, even when the dynamo is running under full load, one may expect to have high bearing losses and, in extreme cases, hot boxes.

39. The **size of the generators** to be used in any plant is a subject that has aroused a great deal of discussion, some favoring a number of small machines and others a few large ones. It is not good practice to have a number of different types and sizes of dynamos in a station, because it multiplies to a great extent the number of repair parts,

brushes, and general stock that must be kept on hand. For example, suppose a station to be equipped with dynamos all of the same make and size. This will mean that even if there are a number of dynamos in the station, one armature and one field, as extra parts, will do for the whole station. Whereas, if the dynamos were all of different sizes or types, one field and one armature must be kept on hand for each. Dynamos of good modern construction seldom lose a field or an armature unless struck by lightning, but they always seem much more apt to do so if the station is not prepared for such an accident. Also, different dynamos call for different brushes, bearings, brush holders, commutators, and wire. These facts are advanced as arguments against the use of a number of small dynamos to take up the required load.

On the other hand, the following points must be kept in mind: A dynamo runs at its greatest efficiency when it runs at or near full load, because, under this condition, most of the work put into it by the steam engine is given out again as useful work; but if the dynamo runs with a light load, it may be that as much work is used in overcoming the internal and frictional losses as is sent out on the line, in which hypothetical case the machine runs at an efficiency of only 50 per cent. If the dynamo is up to speed and its field is excited, but its line switch open, all the work given to the dynamo is wasted; none goes out on the line, so that the machine runs at an efficiency of zero. This goes to prove that any given dynamo or dynamos should be run at as nearly full load as possible, so that the losses may become a small percentage of the total power supplied by the steam engine. This means, in actual practice, that when the load on the station falls off, so that the single dynamo carrying it is only half loaded, it should be cut out and replaced by one of smaller capacity.

Again, for several reasons, a large dynamo at full load is more efficient than a small dynamo at full load; but a large dynamo at half load is not, as a rule, more efficient than one of half the capacity at full load. Also, one large dynamo at full load is much more efficient than a number

of small dynamos whose aggregate capacity is the same as the large one; because in the large dynamo not only are the frictional and internal losses smaller proportionately than those on any one of the small dynamos, but in the case of the large dynamo these losses occur but once, whereas, in the case of a number of small machines, each machine has its own losses and their sum is much greater than the single loss on the large machines. The general conclusion to be drawn, then, is that in the actual operation of dynamos it is best to have the whole station load carried by one generator at full load, or at least to keep those generators that are in operation running as nearly at full load as possible.

40. Use of Compound-Wound Dynamos.—The fact has already been mentioned that compound-wound dynamos are used for operating street-railway systems. In the early days of electric railroading shunt dynamos were used, but they have since been displaced by the compound-wound machines. The reasons for the use of the latter are twofold. In the first place, compound-wound dynamos will operate well in parallel if they are properly installed. In the second place, they have the valuable property of holding the voltage constant or even increasing it as the load is applied; whereas, with the shunt machine, under similar conditions, the voltage will fall off unless field resistance is cut out. Compound-wound dynamos used for operating railways are the same, as regards their construction and connections, as those used for lighting or other kinds of work; hence, what has already been said in regard to compound-wound machines in general applies equally well to railway generators.

41. Overcompounding.—If a power station is equipped with ordinary shunt dynamos, the distribution of load among the several machines must be regulated either by means of shifting the brushes or by the field rheostats; but compound-wound dynamos are not supposed to require any such hand regulation. Once adjusted, under the proper conditions, they will not only share the load proportionately

among themselves, but they will keep the voltage, at a specified point, up to normal value, without any further adjustment of the rheostats, because any increase in the load that would cause the terminal voltage on an ordinary shunt dynamo to drop must pass through the series coils and strengthen the field, thereby restoring the voltage to normal value. Nearly all railway generators are **overcompounded**, i. e., the voltage rises as the load increases. This increase in voltage at the machine terminals is usually from 10 to 20 per cent.; that is, if the normal voltage on an open circuit is 500 and the dynamo at full load gives a terminal voltage of 550, the machine is said to be 10 per cent. overcompounded; if the full-load terminal voltage is 600, the machine is 20 per cent. overcompounded. A compound-wound dynamo will hold the voltage constant at only one point, so that if the machine is overcompounded to hold the voltage constant at some point out on the line, the voltage in the station will move up and down; and if it is compounded to keep the station voltage constant, the voltage at points out on the line will vary.

In spite of the fact that a railway system may be supplied by a good machine heavily overcompounded, it is quite common to see the voltage on removed parts of the system vary between wide limits; in some cases the car lamps almost go out every time a car is started or the speed of a car increased. That such a state of affairs exists is in no way due to a fault in the dynamo. If the dynamo is compounded to look after a 10- or 20-per-cent. loss in the line, it cannot be expected to look after a 40- or 50-per-cent. loss due to a poor rail-return circuit, nor can it be expected to compound at some point 4 or 5 miles farther out on the line than it was originally adjusted for. As a rule, compound-wound dynamos have a shunt in multiple with their series field, as already explained. If this shunt works loose, the greater part of the current will flow through the series field and the dynamo will overcompound more than it should. On the other hand, if a series-field connection becomes loose or the shunt short-circuited, the series field will be weakened and

the dynamo will fail to overcompound as much as it should. How much the dynamo will overcompound depends on the relative resistances of the series-field coils and the series-field shunt with which they are in multiple. Any change in this relation also changes the degree to which the dynamo will overcompound.

42. Connections for Compound-Wound Generator. Fig. 15 is a sketch of the connections of an ordinary four-pole railway generator. The machine indicated in Fig. 15 has four poles and four brush holders, but it has only two armature terminals, because alternate brush holders are

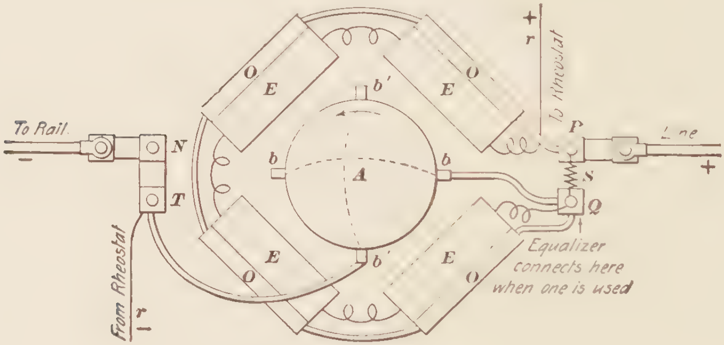


FIG. 15.

connected together by means of a half circle copper strip. If the machine had eight or ten poles and eight or ten brush holders, it would still have only two armature terminals, because all brushes of the same polarity would be joined together.

It will be noticed that each field coil is divided into two sections—a thin section next to the frame and a thick section next to the armature. One section is the fine-wire shunt field and the other section is the series field, which is usually wound with copper strip. The two sections are not only carefully insulated from the frame of the dynamo, but are insulated from each other. They are put on the spool

alongside of each other, so that in case of trouble in one section, it can be taken off without disturbing the other section. Sometimes the shunt coils are placed next the yoke and the series coils next the armature, but it makes no difference, as far as the operation of the machine is concerned, in what relation they are placed.

43. In Fig. 15, *A* represents the commutator; *O*, the series field; *S*, the shunt to the series field; *E*, the shunt field, and *r*, *r* the lines leading to the rheostat for varying the strength of the shunt field. *P* and *N* are the terminals; one goes to the trolley wire and the other to the rail. The actual arrangement of the connections will of course vary somewhat with different makes of machines, but this sketch will serve to illustrate the general arrangement. One end of the fine-wire field connects to block *Q* by means of a small connecting screw, and the other end passes to the field rheostat and comes back to the negative side of the dynamo at block *T*. The cable on the right, marked "Line," leads from the positive side of the dynamo to the trolley wire; the line cable on the left comes from the rail. The current, therefore, goes out of the dynamo on the right-hand side and goes into it on the left-hand side. Coming out of the armature by way of the *b*–*Q* armature terminal, it splits into three parts as soon as it gets to block *Q*. One part takes the path *Q*–*E*–*E*–*E*–*E*–*r*+, through the field rheostat and back to the negative side of the dynamo by way of the rheostat wire *r*–, to block *T*. Another part takes the short path *Q*–*S*–*P* through the series-field shunt *S* to block *P*, while the third part reaches block *P* by way of the path *Q*–*O*–*O*–*O*–*O*–*P*, thus flowing through the series coils.

44. Connecting Field Coils of Compound-Wound Generators.—One very necessary point to look after in connecting the fields of any dynamo is to see that the shunt field is so connected that the machine will pick up and hold its voltage on open circuit; also, that the series and shunt fields are connected so that they will be of the same polarity

and therefore help each other; i. e., so that they will both tend to magnetize the field the same way. If, in Fig. 15, the top shunt-field wire is made to exchange places with the bottom shunt-field wire—that is, if the E–Q fine wire is run to the field rheostat and the E–r+ fine wire is made to take its place at Q—the effect will be to reverse the polarity of the shunt field, and the machine will refuse to generate on open circuit, unless the direction of rotation of the armature is reversed.

45. The Series-Field Shunt. — The use of a shunt across the series field to regulate the effect of the series coils has already been mentioned, and railway generators are usually provided with such shunts. This shunt is generally made of German-silver ribbon. German silver is used because not only is its resistance high, but this resistance remains comparatively constant throughout wide variations in temperature. The strips are folded back and forth, as shown in Fig. 16, well wrapped with heavy tape, and painted with insulating paint. The shunt is also provided with

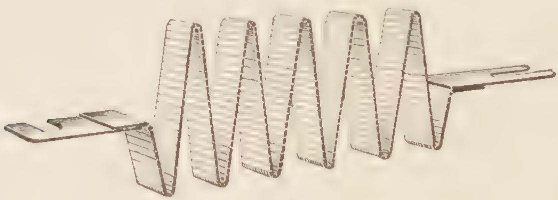
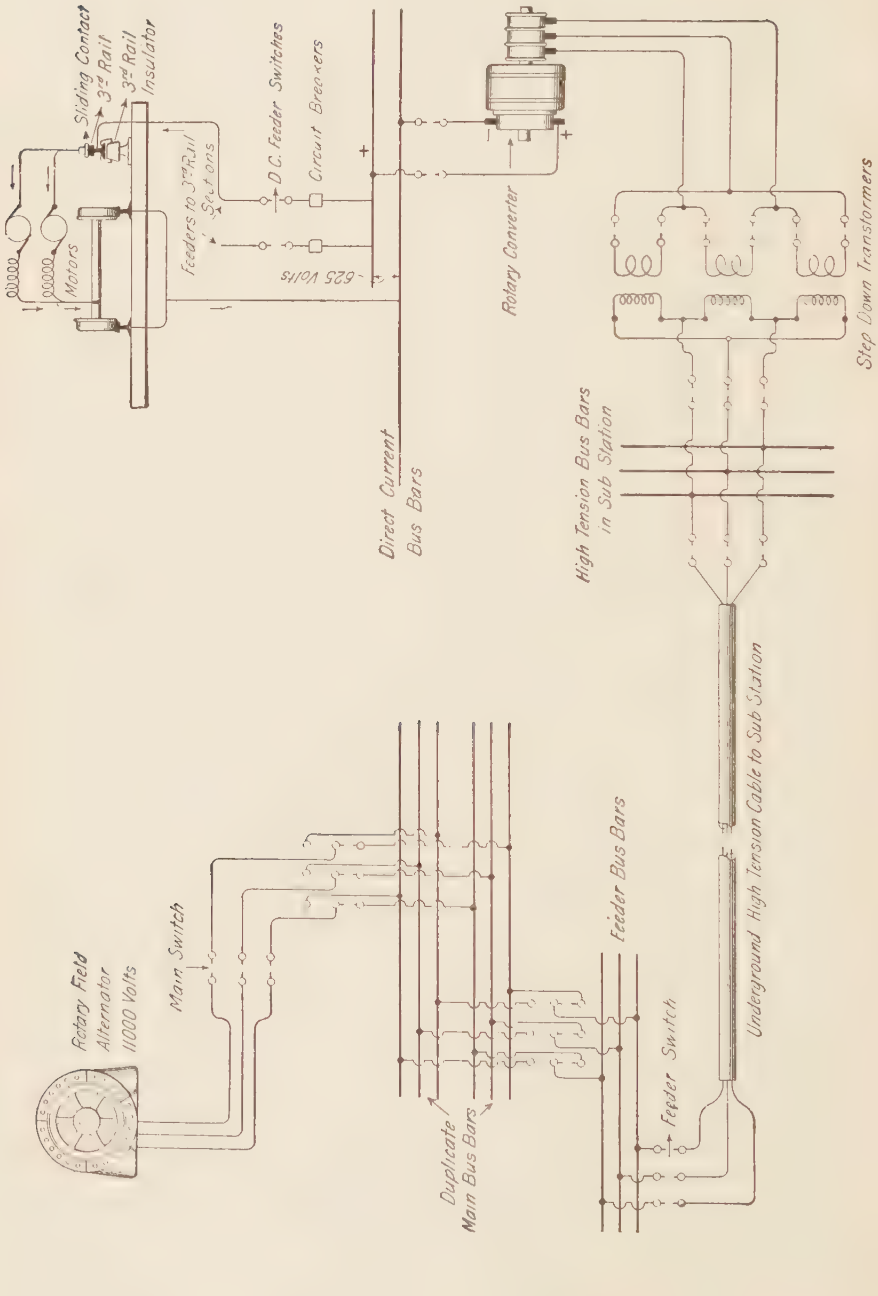


FIG. 16

terminals on the ends. The shunt should always receive its final adjustment after the dynamo is heated. A dynamo adjusted for a certain amount of compounding while it is cold will fall short of this amount after it is hot. This is due to two main causes. In the first place, the shunt field loses strength as it gets hot. When a machine is compounded properly, its voltage is adjusted to normal value on open circuit; the shunt coils supply a field to generate this voltage, which should, without further regulation, remain the same for any length of time. If the open-circuit

adjustment is made while the fields are cold, their resistance increases as they become heated and this cuts down the field current, thus decreasing the magnetizing power. This can be proved by adjusting the open-circuit voltage to 500 while the dynamo is cold, letting it run an hour or so on open circuit, and again trying the voltage; it will be found to be much lower. Again, when the series coils are cold, they have a certain resistance, and the shunt across the series coils is adjusted accordingly to bring the full-load voltage to the desired value. Let us assume, for example, that the German-silver shunt and the series coils with which it is in multiple have the same resistance, so that each takes the same amount of current. Now, the shunt is outside, exposed to a free circulation of air, and if it is properly proportioned, its temperature will change very little from no load to full load, and even if the temperature changes considerably, the change in resistance will be so small that it can almost be neglected. On the other hand, the series coils are buried inside the field spool, where the facilities for radiation are poor, and their resistance increases materially; the result is that the hotter the machine gets, the greater becomes the disparity in resistance between the series field and its shunt.

46. A dynamo tender should know in what position to place the field-rheostat handle bar, in order that the machine will generate normal voltage on open circuit after it has become heated. It is true that a dynamo adjusted to compound to a given degree hot will overcompound when cold, but this condition does not last long enough to do any harm. Besides, the tender should not, when the machine is cold, advance the rheostat handle bar at once to the position that will give the normal voltage when hot. The bar can be gradually worked around to that position as the fields become heated. In a great many cases, the full benefit of a dynamo's compounding property is never made use of. Especially is this so where there are several compound-wound dynamos to be run in multiple on the same load. An



Sliding Contact
3rd Rail
3rd Rail Insulator
D.C. Feeder Switches
Circuit Breakers
Feeders to 3rd Rail Sections
Motors
625 Volts
Rotary Converter
Step Down Transformers
Direct Current Bus Bars
High Tension Bus Bars in Sub Station
Underground High Tension Cable to Sub Station
Feeder Bus Bars
Feeder Switch
Duplicate Main Bus Bars
Main Switch
Rotary Field Alternator 11000 Volts

FIG. 17.

attendant will look at the ammeters, see that one dynamo is taking more or less load than it should, and immediately proceed to give its rheostat bar a twist to even up the load. In a little while it will be necessary to give that same bar or some other one another twist, and so on. It is very often the case that the existing conditions are such that to make the dynamos share the load properly, this practice must be resorted to. If such conditions exist, they should be changed. The station should be compounded as a unit. After a rheostat is once adjusted to make its machine give normal voltage on open circuit when hot, it should not be necessary to disturb it afterwards.

ALTERNATING-CURRENT MACHINERY FOR RAILWAY WORK.

47. Alternators.—The use of alternating current for the operation of electric railways has already been referred to. Some very large systems are now operated by alternating current, among which may be mentioned the Metropolitan Railway and Manhattan Elevated systems in New York and the Central London Underground. Most of the large systems that spread over a wide area are now being operated by distributing the power from one main central station to a number of substations, where the alternating current is changed to direct current, which is supplied to the cars. To carry out such a scheme of transmission, two-phase or three-phase alternating current is used, the latter being the more common. The current at the main station is usually generated by large revolving field alternators, because this type admits of a high pressure being generated in the machine and avoids the use of step-up transformers at the station. Where water-power is available, the alternators are direct-connected to turbines.

48. Fig. 17 shows the general scheme of distributing current for the Manhattan Elevated Railway, New York, and will serve to illustrate the general method of distribution referred to above. Current is generated in one large

central station by revolving-field, three-phase alternators direct-connected to 8,000-horsepower engines. The use of the revolving-field type of machine enables the current to be generated at 11,000 volts in the machine. It is distributed to a number of substations by means of heavily insulated lead-covered cables run in underground conduits. At the substations it is passed through stationary transformers that step down the voltage. The rotary converters

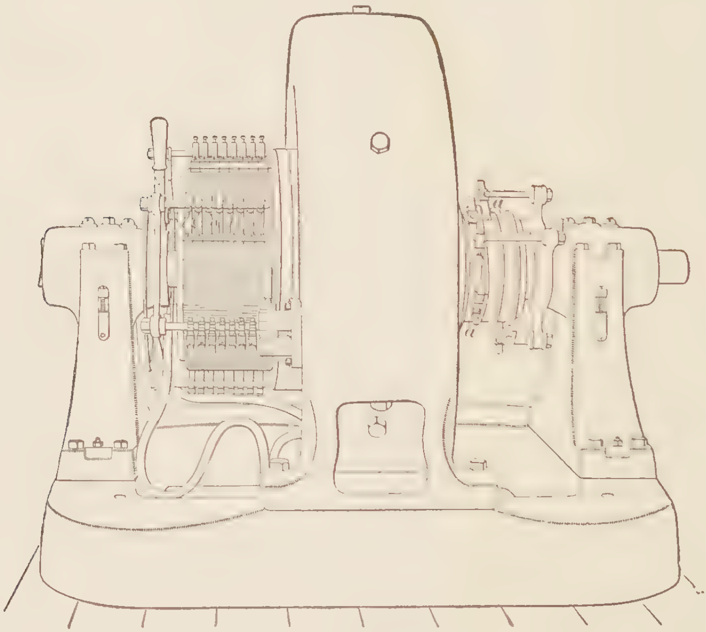


FIG. 18.

change the alternating current to direct current at about 625 volts, and from the substations it is supplied to the cars by means of a third rail and the ordinary track. The systems of distribution used by the Metropolitan Railway Company, of New York, and the London Underground are almost exactly the same as this one, except that the distributing pressures are somewhat lower. In the case of the Metropolitan road the distributing pressure is 6,600 volts.

49. Rotary Converters.—As before mentioned, alternating current is used comparatively little to propel the cars themselves, but is first changed to direct current by means of rotary converters. Fig. 18 shows a three-phase rotary converter designed for railway work; it is a six-pole machine of 300 kilowatts capacity. The high-pressure alternating current from the line is first run through step-down transformers and then supplied to the rotary through the collecting rings *a*, *a*; the direct current is supplied to the cars from the commutator side. Rotary transformers are not provided with a pulley, because no outside source of mechanical power is required to drive them.

50. Double-current generators are machines that generate both alternating and direct current. In appearance they look almost exactly like a rotary converter, except, of course, that they are provided with a pulley or are direct-connected, so as to be driven from an outside source of power. Their whole output may be utilized as direct current, as alternating current, or as a combination of the two. These machines have been used to some extent in stations where a part of the power must be used close at hand and a part transmitted for a considerable distance. The part of the railway near the station is supplied from the direct-current side and the distant part is supplied through step-up transformers from the alternating-current side. These machines generate between 500 and 600 volts direct current, so that the alternating-current voltage is comparatively low and step-up transformers must be used to obtain the high pressure necessary for transmitting the power over long distances.

51. Alternating-Current Motors for Railway Work. Polyphase induction motors are in successful use on a few European electric railways, and it is not improbable that these motors will be more used in the future. Those that have been used are the same in their essential parts as the ordinary stationary induction motor, but are cased in and

have about the same general appearance as ordinary direct-current motors, which are to be described later. They give a good starting effort, but take considerable current from the line in so doing. Their speed is usually controlled by having an adjustable resistance in the armature circuit. Those that have been used are of the three-phase type, and hence require three wires for their operation; the track answers for one of these, so that two trolley wires are necessary. In some installations three trolley wires have been used. Induction motors would be well suited for suburban lines where the overhead work would not be complicated and where it might be allowable to use a high pressure between the trolley and the rail. Induction motors could be wound for higher pressures than direct-current motors, because they have no commutator to give trouble. It is quite possible that they may come into use for suburban, elevated, and underground work, in which case the necessity of rotary converters would be done away with, and in some cases even step-down transformers would not be needed.

RAILWAY SWITCHBOARDS.

52. Switchboards are used for centralizing the many circuits used to distribute the power, and in this capacity are called on to hold the switches used in making the various connections and combinations, the instruments used for controlling and measuring the loads on these circuits, and the various protective devices necessary to insure that the expensive apparatus shall not be injured by abnormal conditions arising either in the station or out on the lines. In the earlier railway days it was the practice to string incoming and outgoing wires along the walls of the station and to mount the various devices, bus-bars, etc. upon the face of a wooden switchboard placed right up against a wall, in a position selected with no particular end in view of having the switchboard with its measuring and indicating devices

anywhere near the engines and dynamos. The tendency of today is to spare nothing in the effort to have the switchboard well constructed and convenient in every way, and many of the boards now built are models in this respect. It has taken time, however, for this change to be brought about. Dynamos in their present state of perfection do not give nearly as much trouble as the older types, and on account of the state of perfection reached by the various protective and safety devices, no trouble can do the damage and cause the shut-downs that were once so common.

The switchboard, if properly arranged, is a great time and labor saver; it enables each dynamo and each circuit to be used as a separate unit; where occasion demands such practice, one dynamo can be thrown on to several circuits, and any or all of the dynamos can be cut out of circuit. All these combinations may be effected, if necessary, without the man that does it going near the dynamos.

53. Location of Switchboard.—It generally falls to the lot of the road engineer to decide where the board shall be placed in the station, and this is no easy matter, as so many different requirements must be reconciled. The tendency of the day in large stations is to have one man give all his time to the operation of the switchboard and do absolutely nothing else. In very large stations, where large currents are handled and large units must be used, it keeps one man busy watching the total station load and the individual dynamo loads, to see that just enough and not too many dynamos are in operation to care for the load, and that no dynamo is taking more than its share. On the smaller roads, however, it is, as a rule, the duty of one of the engineers to operate the switchboard.

Among other things, the location of the switchboard is fixed by the relative position of the dynamos and engines. The switchboard should be so placed that there will be no necessity for the engineer, in case trouble occurs at any point or in case he must get to the throttle of an engine, to go through a belt or down a flight of stairs. The life risk

should be kept in mind above all other considerations. After this, perhaps, comes a consideration of the economy side of the question. If the board is very far from the dynamos, the drop in the connecting wires will be considerable, and the machines are apt to equalize badly unless the

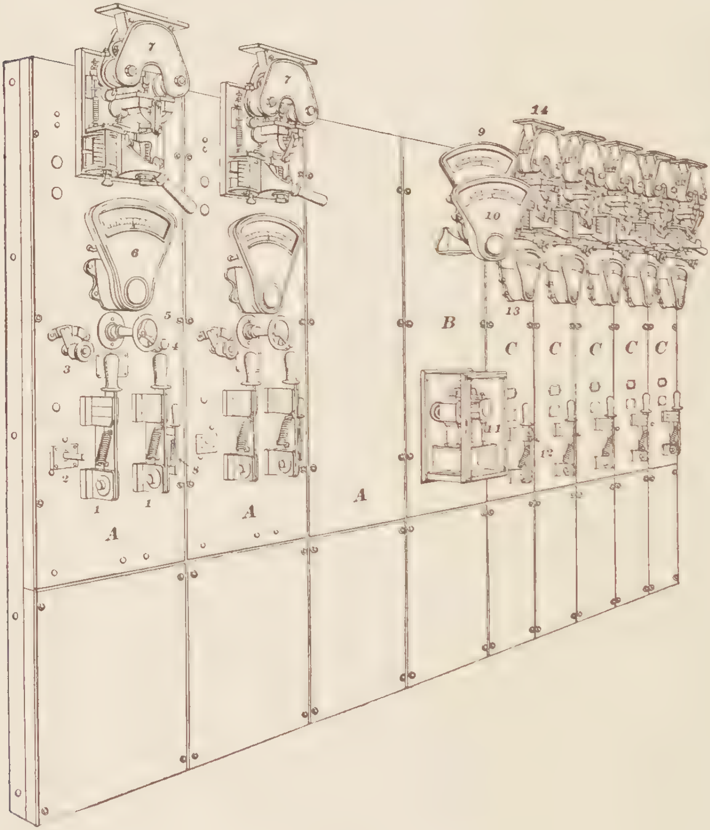


FIG. 19.

equalizing wire is run directly between the machines and not carried to the switchboard at all. When dealing with small currents, the question of drop in a large wire almost escapes notice, but when we deal with currents of several

thousand amperes, such losses become an important item and care must be taken to reduce them to a minimum.

54. Materials Used for Railway Switchboards.—Railway switchboards, like all other modern boards, are made of fireproof material throughout. The board itself is usually made of slate or marble about 2 inches thick, and is bolted to vertical angle irons. The instruments are mounted on the face of the panel, and all connections between them are made on the back. The board is stood out from the wall or mounted in such a way that the back shall be easily accessible in case it is necessary to do work on any of the connections. Fig. 19, shows a typical railway switchboard for handling 500-volt direct current. This board is made of three *generator panels A*, *A*, *A*, one *total output panel B*, and five *feeder panels C*, *C*, etc. Only two of the generator panels are equipped with instruments, the third being left blank to accommodate a third machine when it is installed. Generator panels are usually about 24 to 30 inches wide and feeder panels 16 inches; the total height of the board is 90 inches.

55. Equipment of Generator Panels.—Each generator panel carries the switches and instruments necessary for the generator to which it is connected. These are as follows: *main switches 1*, *1*, *voltmeter plug 2*, *field switch 3*, *pilot-lamp receptacle 4*, *field rheostat 5* (the rheostat itself is mounted on the back of the board with the operating handle in front), *ammeter 6*, and *circuit-breaker 7*. The small switch *8* is used for controlling any station lights or motors that may be operated from the machine.

56. Equipment of Total-Output Panel.—This panel is not always provided, but it is generally installed in the best plants. It generally carries the *voltmeter 9* and a *total-output ammeter 10*, which is connected so that it indicates the total combined current delivered by all the generators. This panel is also equipped with a *recording wattmeter 11*, which measures the total number of watt-hours delivered by

the station, so that an accurate account may be kept of just what work the station is doing.

57. Equipment of Feeder Panels.—The feeder panels are supplied with the equipment necessary for the control and measurement of the current on the different feeders going out from the station. Each panel is equipped with a *feeder switch 12*, a *feeder ammeter 13*, and a *circuit-breaker 14*. On some boards the feeder panels are not equipped with ammeters.

58. General Remarks.—The advantages of the panel type of construction are that it groups the apparatus belonging to each individual part of the plant by itself; also, it allows the board to be extended easily in case the plant is enlarged either by adding more feeders or more generating apparatus. As a rule, only one voltmeter is necessary, because by means of the plug *2* the instrument may be connected to any machine in case a reading is desired. Some boards, however, have two voltmeters, one of which is permanently connected across the bus-bars and the other arranged so that it may be connected to any machine. This is a convenient arrangement where a machine is being thrown in multiple on the bus-bars, but it is not essential that the board should be equipped in this way. The voltmeter is often mounted on a swinging bracket, as in Fig. 19, so that it may be readily seen by the operator. In case a total-output panel is not provided, the voltmeter is often mounted on a swinging arm at one end of the board. In addition to the apparatus shown in Fig. 19, each generator panel, and in some cases the feeder panels also, is equipped with lightning arresters mounted behind the board.

RAILWAY SWITCHBOARD APPLIANCES.

59. Main Switches.—Before considering the connections necessary for a railway switchboard, we will take up the various appliances used on the board. The *main*

switches shown at *1*, *1* are, of course, intended to disconnect their generator from the bus-bars. These switches should be of substantial construction, as they are called on to carry a heavy current. They are usually made so as to give a quick break and thus prevent arcing. In general, however, the main switches are not used to open the circuit when the machine is carrying a load. If it is necessary to do this, the circuit-breaker should be used, because it is constructed so that it will break the circuit without any injurious arcing. Single-pole switches are generally used on railway boards. In Fig. 19, two main switches are shown on each generator panel, though it is quite common to find three switches. If the equalizer wire is run to the switchboard, then three switches are used, but if it is run between the machines, as is done in the more recent installations, only two switches are necessary on the board, and the equalizer switch is mounted on a stand near its dynamo.

60. Voltmeter Plugs and Switches.—These are used to enable the voltmeter to be connected to any one of the generators. For railway boards, a plugging arrangement is generally preferred to a switch, as it is less complicated and more substantial. The plug is arranged so that when it is inserted as shown at *2* on the first panel, Fig. 19, it connects the voltmeter *9* across the dynamo connected to the first panel. The way in which this is carried out will be apparent when we come to take up the switchboard connections.

61. Field Switch.—The field switch is used to open the shunt-field circuit of the generator; it is, therefore, of comparatively small current-carrying capacity. The shunt-field winding of a railway generator consists of a great many turns of wire, and it must not be forgotten that if the shunt-field circuit is suddenly broken, an exceedingly high E. M. F. will be induced in the winding, due to the sudden decrease in the magnetization threading through the field coils. The field switch must, therefore, be arranged to take up any discharge from the field, otherwise the high induced voltage may puncture the insulation on the field spools.

Fig. 20 shows the arrangement of the field switch and pilot lamp used on the board in Fig. 19. The switch S has two contact segments a, a', and the tongue t is wide enough to bridge over the gap between them. The switch is shown in the position that it occupies when the generator is in operation. The current then passes through the field rheostat r and the switch S as indicated by the arrowheads. When the switch is moved to the position indicated by the dotted line, connection between the field and the negative side of the armature is broken, but before the break takes place, tongue t comes into contact with a', so that the shunt field, the rheostat r, discharge resistance r', and pilot lamp l all form a closed circuit. The shunt field is thus able to discharge through this closed circuit, and danger of puncturing the insulation is avoided. When the machine is being started, the tongue t is placed in its mid-position, so that current can flow through r' and l as well as through the shunt field and rheostat r. As the machine builds up, the pilot lamp becomes brighter, thus giving the attendant an indication as to whether the machine is "picking up" properly or not. After the machine has come up to voltage, the switch is moved to the position shown in the figure and the pilot lamp is cut out. On some boards, five or six lamps in series are used in place of the resistance r' and the single lamp l. The pilot lamp l is inserted in the receptacle 4, shown in Fig. 19.

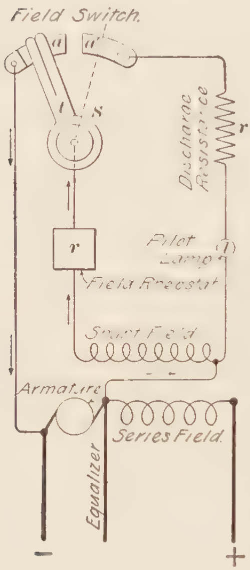


FIG. 20.

62. Field Rheostats.—Field rheostats, or resistance boxes, are used in connection with all railway generators, and are connected in series with the shunt-field winding, so that the field current, and hence the voltage of the generator,

may be adjusted. The field resistance is not intended to be used for regulating the voltage to suit the variations in load, because the compound winding is supposed to take care of that. It is used to adjust the voltage when the machine is first started, and it is also necessary to cut out some of it as the field coils warm up.

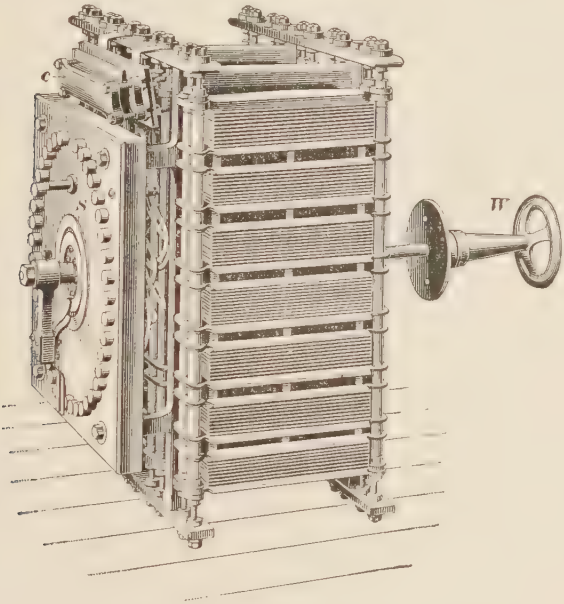


FIG. 21.

Field rheostats used on railway boards are made in a great variety of designs, but in all cases they consist of a resistance split up into a large number of sections that are connected to a multipoint switch, so that any amount of resistance may be cut in or out. In some styles the resistance is made up of German-silver or tinned-iron wire coiled into spirals and mounted in a well-ventilated iron box. In others, the wire is formed into zigzag shape and mounted in enamel on the back of cast-iron plates. In all cases, rheostats should be constructed so that they will be perfectly fireproof and at the same time allow easy radiation of the

heat generated in them. If the latter point is not considered, burn-outs are apt to result. In some rheostats the resistance is in the form of cast-iron grids of zigzag form. This makes a substantial resistance that is well ventilated and is especially suited to rheostats of large capacity.

63. When rheostats are of comparatively small size, they are mounted on the back of the switchboard and operated from the front. Fig. 21 shows a type used by the General Electric Company on railway boards and arranged for mounting on the back. The switch is shown at *S* and is operated by the wheel *W* on the front of the board. In this particular rheostat, the resistance wire is wound on sheet-asbestos cylinders, which are afterwards flattened and clamped between pieces of sheet iron covered with asbestos. The wire is thus held firmly in place, and the pieces of iron nearest the wire serve to radiate the heat. To allow the voltage to be regulated by small steps, it is necessary to have a considerable number of points on the rheostat switch. Another method of accomplishing the same result is to have a small resistance connected to the switch arm, so that it will be put in multiple with each step as the arm is moved around. This scheme is used in the rheostat shown in Fig. 21, and will be understood by referring to Fig. 22. The regular rheostat contacts are arranged as usual and are shown at *1*, *2*, *3*, etc. Instead, however, of using a simple contact arm, the arm is provided with two contact tips *a*, *a′*, insulated from each other, and which press on the contact rings *b*, *b*; *c* is a small so-called multiplying resistance (see also *c*, Fig. 21), which is

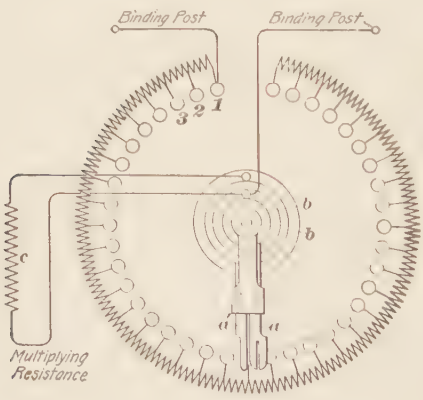


FIG. 22.

approximately equal to one of the resistance sections on the rheostat. By tracing out the current, it will be seen that *c* is placed in parallel with the step on which the arm rests, and it has the effect of practically halving the resistance of each step as the arm is moved around; it, therefore, gives as fine an adjustment as though the rheostat were provided with a single arm and twice the number of steps.

When very large generators are used, the rheostat is generally mounted separately from the switchboard. In some cases, the switch is placed on the back of the board and is connected by wires running to the resistance, which may be mounted in any convenient location. In other cases, the rheostat and switch are both mounted away from the board and are controlled by a shaft fitted with bevel gears, or by a chain-and-sprocket arrangement. This arrangement is preferable to running wires from a rheostat switch on the board to the rheostat itself.

64. Ammeters.—Each generator should be provided with an ammeter that will indicate its current output. It is also advisable to have an ammeter in each feeder. The load on a railway generator fluctuates rapidly, and it is essential that the ammeters should be "dead-beat"; i. e., the hand should not swing back and forth, but should move to its place whenever there is a change in the current and it should stay there until another change takes place. The instrument should also be constructed so that it will require but a small amount of energy to operate it. This may seem a rather unimportant point, but where a station has a large number of instruments that are in circuit all the time, the amount of energy used in them in the course of a year may be considerable.

Weston ammeters are very largely used for railway boards. They are accurate, consume but little energy, and are dead-beat. The switchboard type used for railway work is exactly similar in principle to the portable type, but much larger. The main ammeters and voltmeters are

provided with dials that are illuminated from the rear, so that they may be easily read. Feeder ammeters are not usually provided with illuminated dials.

65. Voltmeters.—At least one voltmeter is necessary on every railway switchboard, and it should be arranged so that it may be connected to any machine or to the bus-bars. The voltmeter is, of course, connected across the circuit, and it should therefore have a very high resistance, or else it will take considerable current. Voltmeters and ammeters are generally the same in appearance and the operating parts are the same, but the voltmeter has a very high resistance compared with that of the ammeter.

66. Westinghouse Railway Ammeters and Voltmeters.—On the earlier types of Westinghouse switchboards, ammeters and voltmeters of the plunger type were used. The current was led through a vertical coil or solenoid that was arranged so as to pull down an iron core hung from one side of a balance arm to which the pointer was attached. On their later boards, the Westinghouse Company use a round-style instrument, in which the current flowing in the coil acts on an iron vane placed within it, instead of on a plunger.

67. Thomson Astatic Ammeters and Voltmeters.—These instruments, invented by Professor Elihu Thomson, are used by the General Electric Company. The board shown in Fig. 19 is equipped with instruments of this type. In the Thomson astatic meters, electromagnets are used to set up the magnetic field instead of permanent magnets, as in the Weston instruments. Also, the moving coils are mounted on an aluminum disk instead of being made in rectangular shape. The retarding force acting on the armature is not supplied by spiral springs, but is provided for by the attraction of the field magnets for small iron vanes placed on the moving member. If, for any reason, the electromagnets become weaker, the force acting on the

movable coils, for a given current flowing through them, also becomes weaker, but the retarding force decreases at the same time, so that the reading of the instrument is not affected. A Thomson astatic ammeter, as used on a generator panel, has six wires running to it; two of these run to the ammeter shunt, the same as for a Weston instrument; two others run to the bus-bars, so as to supply the field electromagnets with exciting current. These magnets are provided with a high-resistance winding, so that they may be connected directly across the line. The third pair is used to supply current to the lamps used for illuminating the dial. The ammeters used on the feeder panels do not have illuminated dials, hence these last two wires are not required.

CIRCUIT-BREAKERS.

68. On the first railway boards that were brought out, fuses were used to protect the machines from overloads, but it was soon found that while these might be fairly well suited to lighting or other work where the machines were not subject to violent overloads, they were not reliable for railway work, and, moreover, the renewing of blown fuses was a nuisance. Fuses have, therefore, been replaced by automatic circuit-breakers, of which there are several different makes. Those that have been most widely used for this service are the General Electric, the Westinghouse, and the Cutter, or I. T. E., as it is sometimes called.

The circuit-breaker, as this name is now accepted, is automatic in action and is designed to open or break the main working circuit whenever, for any reason, the current reaches a value that is not safe for the dynamos to carry. It is not a difficult matter to get up a device that will break the current at a set value for the first few times that it is operated, but it took years of study and observation in actual practice to perfect a device that would not burn and blister itself into a worthless condition in a short

while when used continuously. The circuit-breaker, to be effective, must be able to break heavy currents without damage from the burning effect and this means that the arc must be almost instantly extinguished as soon as the breaker opens.

69. General Electric Type M K Circuit-Breaker.—This is a type of breaker that has been very extensively used in railway work. In it the arc is extinguished by breaking the circuit in a magnetic field. It is a well-known fact that a wire carrying a current in a magnetic field tends to move across the field, this, in fact, being the principle of operation of the electric motor. An arc formed by the current between two terminals acts exactly like a wire carrying a current; hence, if the arc is made to take place in a magnetic field, it will be forced across the field and stretched out so that it is broken. This action is almost instantaneous, and if the magnetic field is fairly strong, the arc is blown out almost as soon as it is formed. This magnetic blow-out method of suppressing arcs is largely used in car controllers, lightning arresters, and other devices.

70. Fig. 23 shows the General Electric Company's M K breaker, which is the kind also shown on the board, Fig. 19. This type has been selected for illustration on account of its ready adaptability to almost any class of service and on account of its wide range of adjustment. M K breakers can be had of any capacity from 150 to 8,000 amperes, and are therefore equally suited to feeder or to individual generator duties. In Fig. 23, *B* is a heavy tripping coil of copper, through which passes the main current that operates the breaker. The main current enters the coil through the rear connecting post *A*; from the coil it passes to a connection on the back of the heavy copper contact block *C*. When the breaker is closed ready for service, as shown in the figure, the main current passes from *C* to the curved copper bridge *D D* and out to the line again through the heavy block *E*, which has a terminal like *A* in

the rear. When the breaker is closed, the hinged iron armature F is held up by a spring G, the tension of which depends on the adjustment of a thumbscrew J. Attached to plate F is a trigger H, which has on the under side of its end a shoulder against which a projection on the main handle yoke K

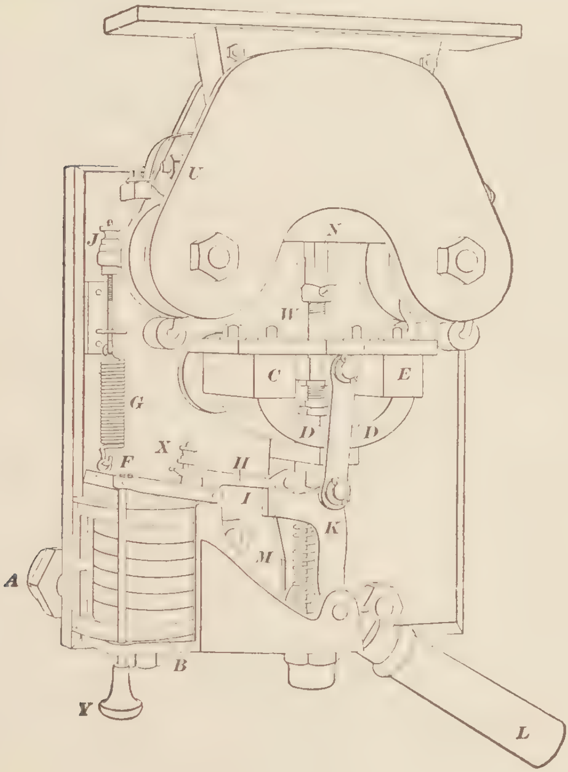


FIG. 23.

bears. To set the breaker, the main handle L is pulled down hard; this forces $D\,D$ up against blocks C and E, and also causes the projection on K to engage trigger H, which holds the circuit-breaking parts in place. In setting the switch, spring M is extended. Now, suppose the current to go above the value for which the breaker is set to operate.

The solenoid B draws down its armature plate F, and with it the trigger H, which liberates the switch yoke and allows the strong spring M to pull down DD, and hence open the circuit at C and E. It can thus be seen that this part of the device is a circuit-breaker within itself, but the arrangement as it stands would provide no means of suppressing the arc, and the blocks C and E and the bridge DD would burn badly. Fig. 24 is a diagrammatic sketch of the path of the main current through the breaker. The tripping coil B, the blocks C and E, and the bridge DD are all in series, forming part of the main

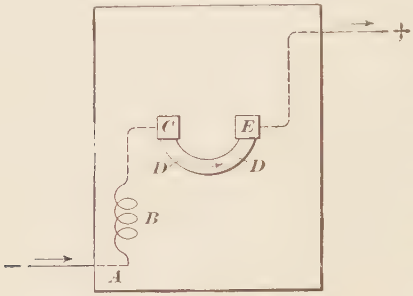


FIG. 24.

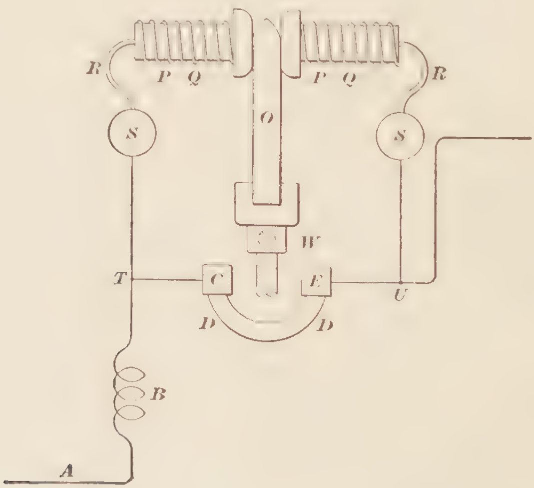


FIG. 25.

circuit. Let us now see how the arc is cared for. By taking the name plate off the breaker, a chamber is exposed that contains an arrangement similar to that shown in

Fig. 25 and constituting what is called the *secondary break;* the break between *C* and *E* and the bridge is the primary break. *P*, *P* are two copper plunge contacts that are impelled towards each other by springs *Q*, *Q*, but which do not touch each other even if *O* is pulled out from between them; the switch tongue *O* is carried on a rod that is actuated by the movement of the main handle *L*, which also works the main bridge contact *D D*, but there is lost motion between contact *O* and contact *D D*, with the result that when the breaker works, *D D* leaves *C*, *E* before *O* leaves *P*, *P*. *S* and *S* are two coils that provide a powerful magnetic field across the place where the tongue *O* leaves the contacts *P*, *P*. By means of strips *R*, *R* each of the coils is connected to the *P* contact nearest to it. It can be seen, then, that the two coils *S*, *S*, the two contacts *P*, *P*, and the contact *O* are in series. When the breaker is set, *O* connects *P* and *P*, and *D D* connects *C* and *E*, so that when current entering the breaker at *A* gets to point *T*, it has a choice of two paths by means of which to reach point *U*; one path is straight across *T–C–D D–E–U*; and the other path is *T–S–R–P–O–P–R–S–U*. The primary and secondary paths, then, are in multiple. When the breaker is set, however, the resistance of the secondary path is comparatively so high that it takes little or no current. As soon as an overload causes the tripping coil *B* to trip the trigger *H*, *D D* leaves *C*, *E* at once, with very little arcing, because the current has still a good path through the secondary circuit. The same movement that pulls bridge *D D* from blocks *C*, *E* withdraws tongue *O* from between contacts *P*, *P*, a little later, however, so that although the circuit is open at *D D*, there is, nevertheless, an arc holding across *P*, *P*. The strong magnetic field across *P*, *P*, however, soon forces this arc upwards and breaks it, all smoke and gases being driven out through a draft hole in the top of the chamber that encloses the device. Frequent actions will, in course of time, deposit on the walls of this chamber a film of carbon, which, if not cleaned off, will cause a short circuit and will blow up the breaker. Contact blocks *P*, *P* have nuts by

means of which the air gap between them can be adjusted. One of these nuts can be seen at *U*, Fig. 23. The stem *W*, Figs. 23 and 25, also has adjusting nuts, by means of which the amount of lost motion between *O* and *D D*, and hence the interval of time elapsing between the break at *P*, *P* and that at *D D*, can be regulated. As wear takes place in any of the connecting parts or as the contacts become burned, some of the lost motion must be taken up in order to preserve the right relationship between the time of breaking in the primary and secondary circuits. Contact bridge *D D* is made up of layers of leaf spring copper, so that it has more or less give to it. The result is that when the breaker is set, the surfaces of the bridge are forced apart a little, thus giving a certain amount of wipe instead of a plain butt contact. It is evident that the stronger the pull exerted on plate *F* by spring *G*, the more force must coil *B* exercise on it, and the greater current must there be in it to draw down the plate and to trip the trigger *H*. The tension on the spring can be regulated by means of the nut seen at *J*. Also, the amount of engagement between trigger *H* and the projection on the yoke *K* can be regulated by means of the thumbscrew seen at *X*, Fig. 23. The pull *Y* is a device used to trip the breaker by hand, whether it has any current going through it or not, and is very convenient when adjusting the time interval between the primary and secondary breaks. All the contacts on the breaker should be examined from time to time, and if any rough projections are present, they should be dressed down with a file.

71. Westinghouse Circuit-Breaker. — Fig. 26 shows the Westinghouse circuit-breaker, of which large numbers are in use, and which have given very good service. No magnetic blow-out is used, but the arc is taken care of by making the break take place at auxiliary carbon contacts, where the burning does no harm, since these contacts can be renewed at small expense. In Fig. 26, *a*, *b* are the main contacts, which are connected by the crosspiece *c*

when the breaker is set. The current enters at *a*, flows across *c* to *b*, thence through the tripping coil *d* and out at *e*. Coil *d* has an iron core that pulls up an armature when ever the current exceeds that for which the breaker is set. This armature is weighted with an adjustable weight *w*, by means of which the tripping point may be adjusted. The auxiliary carbon contacts are in the form of plates *m*, *m* attached to the fixed contacts *a*, *b* and carbon wipers *n*, *n* attached to the breaker arm. The arm is pushed in against the action of a spring and is held in place by a catch. When the catch is released, by the current becoming excessive, the arm flies out. Contacts between *c* and *a*, *b* break first, and the current momentarily flows through the carbon contacts. When the wipers leave the carbon plates the break takes place, so that the burning action occurs on the carbon.

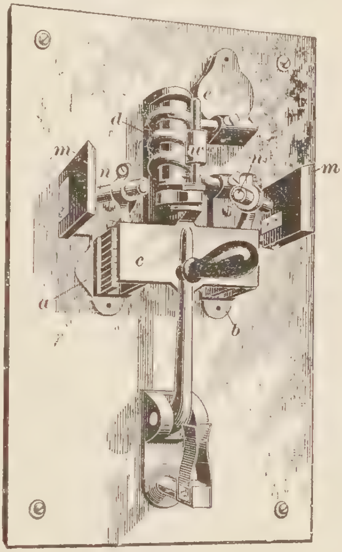


FIG. 26.

72. The Cutter Circuit-Breakers (I. T. E. Breakers). These circuit-breakers are somewhat similar in appearance and action to the Westinghouse breakers. The arcing is taken care of by using auxiliary carbon breaks, but the arrangement of the tripping device is different. In these breakers, the tripping coil or solenoid sucks up an iron core when the current becomes excessive. This core is mounted loosely in the solenoid and is not attached to the trigger, but operates the latter by striking it a blow when it is drawn up. One advantage of this breaker is that there is very little danger of the tripping device sticking and failing to work.

COST OF POWER FOR ELECTRIC RAILWAYS.

Output Measured by Wattmeter in Each Case.

Station.	Month.	Monthly Output. Kilowatt-Hours.	Cost of Electrical Output per Kilowatt-Hour. Cents. Fuel.	Labor.	Supplies, Oil, Waste, Etc.	Water.	Repairs.	Total.	Gals. Cylinder Oil per 10,000 K. W. H.	Gals. Lubricating Oil per 10,000 K. W. H.	Lb. Water per Lb. Coal.	Lb. Fuel per K. W. H.	Price of Fuel per Ton of 2,000 Lb.	Kind of Fuel.
1	Jan.	2,455,060	.322	.111	.029	.029	.044	.535	2.62	.848	10.83	2.45	$2.63	Bituminous
1	Feb.	2,511,280	.334	.114	.036	.027	.025	.536	2.64	.829	10.05	2.54	2.63	"
1	Mar.	2,097,160	.337	.123	.037	.030	.040	.567	2.84	.987	11.21	2.55	2.64	"
1	Apr.	2,158,660	.344	.129	.039	.032	.043	.587	2.98	.722	11.37	2.61	2.64	"
5	Jan.	2,445,161	.408	.110	.013	.011	.016	.558	2.18	1.31	5.51	4.10	1.99	"
5	Feb.	2,512,125	.389	.116	.014	.008	.011	.538	2.50	1.05	5.32	3.89	2.00	"
5	Mar.	2,352,698	.405	.126	.018	.011	.016	.576	2.52	1.70	5.15	4.33	1.87	"
5	Apr.	1,887,029	.347	.149	.020	.011	.036	.563	3.9[illegible]	1.11	5.22	4.22	1.65	"
6	Nov.	827,008	.712	.198	.033	....	.067	1.010	...	.....	.....	2.35	.943*	Oil
6	Dec.	810,728	.709	.198	.024	....	.070	1.001	....	.....	.....	2.36	.937*	"
6	Jan.	643,482	.680	.251	.038	....	.185	1.154	....	.....	.....	2.24	.915*	"
6	Feb.	494,000	.655	.282	.037	....	.181	1.155	....	.....	.....	2.25	.905*	"
6	Mar.	562,574	.761	.266	.031	....	.059	1.117	....	.....	.....	2.42	.976*	"
6	Apr.	616,634	.628	.236	.030	....	.095	.989	....	.....	.....	2.31	.843*	"

* Price of oil per barrel.

COST OF POWER.

73. The cost of generating power in electric-railway plants varies greatly, as one would naturally expect. The actual cost per kilowatt-hour at the switchboard includes so many items that are subject to such wide variation that it is difficult to give even approximate figures relating to cost. In fact in even the same station the cost will be higher during some months than others. The accompanying table, from the Street Railway Review, gives figures relating to the cost of generating power in some stations of considerable size. It should be noted that the total cost covers only the items of fuel, labor, supplies, water, and repairs. It does not allow for interest on the investment or depreciation of the plant. In a large number of plants the total cost, including interest, etc., will lie between 1 and 2 cents per kilowatt-hour, and in some of the largest plants it may be somewhat below 1 cent per kilowatt-hour.

74. The amount of power required to operate each car also varies greatly on different roads, and the cost per car mile is consequently subject to wide fluctuations. For the total operating expenses, including repairs of all kinds, office expenses, cost of labor, etc., per car mile is between 10 and 15 cents on a number of roads. The costs in individual cases might, however, vary widely from the above. The following shows the power consumption for a road operating about 400 cars, most of which were of the large double-truck type, and hence took a comparatively large current.

Average amperes used per car....................	75
Voltage..	500
Kilowatts output per car........................	37.5
Cost of power per kilowatt-hour at power house...	$.02
Cost of power per hour per car	$.75

ELECTRIC RAILWAYS.

(PART 2.)

RAILWAY SWITCHBOARD APPLIANCES.

1. The Recording Wattmeter.—The recording wattmeter is used to measure the total amount of energy delivered from the station. The power, or the rate at which work is done by the generators, is found by multiplying the current by the E. M. F. This gives the watts delivered at the instant at which the readings are taken. The watts multiplied by the number of hours during which they are delivered give the total work done in watt-hours. Since 1 kilowatt = 1,000 watts, the watt-hours divided by 1,000 will give the kilowatt-hours delivered, and, also, since 1 horsepower = 746 watts, the watt-hours divided by 746 will give the horsepower-hours delivered by the station. It would be an easy matter to obtain the output in horsepower-hours or kilowatt-hours for any station if the load remained constant, because all that would then be necessary would be to multiply the ammeter and voltmeter readings together and then multiply the product so obtained by the number of hours the station is in operation. This would give the total watt-hours, which divided by 746 would give the horsepower-hours. This method is, however, seldom practicable, especially in railway stations. If the load is a variable one, it is necessary to take readings at frequent intervals throughout the

For notice of copyright, see page immediately following the title page.

time during which the amount of energy absorbed is sought; then, adding the voltmeter readings together and dividing by the number of readings gives the average voltage during the time, and adding the current readings together and dividing by the number of readings gives the average current during the time under test. These two average values for the current and for the voltage, multiplied together, give the average watts, and this multiplied by the number of hours gives the watt-hours output. Where, however, the variations in load are very violent and sudden, the energy consumption for any given period of time obtained in this way is not always to be relied on, so it is necessary to use an instrument that will average up the energy delivered to the lines, and for this purpose a recording wattmeter is used on the switchboard in the best equipped stations. The Thomson meter is generally used for this purpose. The instrument used on railway switchboards is the same in principle as that previously described, though, of course, the design is considerably modified to suit it to the heavy currents that it has to handle.

2. A Thomson recording wattmeter as designed for switchboard work is shown in Fig. 1. The series coils of the ordinary meter are here replaced by the heavy copper bar *a*, through which the whole current output of the station passes, connection being made on the back of the board to the lugs *b*, *b*. Above and below this bar are the two small armatures *c*, *c*, which are connected in series with a resistance across the line, so that the current in them is proportional to the voltage. Current is led into the armatures through a small silver commutator *d*, as in the ordinary recording meter, and the reading is registered on a dial *e* in the usual way. The damping magnets used to control the speed are contained in the case *f*. The main current flowing through the crosspiece *a* sets up a field surrounding it, and this field acts on the two armatures *c*, *c*. The current in these instruments is so large that a sufficiently strong magnetic field is produced by passing the current through

what is practically a portion of one turn only, whereas in the small meters several turns are required. The reading (watt-hours) is obtained in the same way as for the ordinary style of meter, and by keeping a record of the readings, the output of the station for any given interval of time may be readily obtained. This instrument is constructed so that outside magnetic fields have little or no influence on it. On some of the older styles of meters, the magnetic field

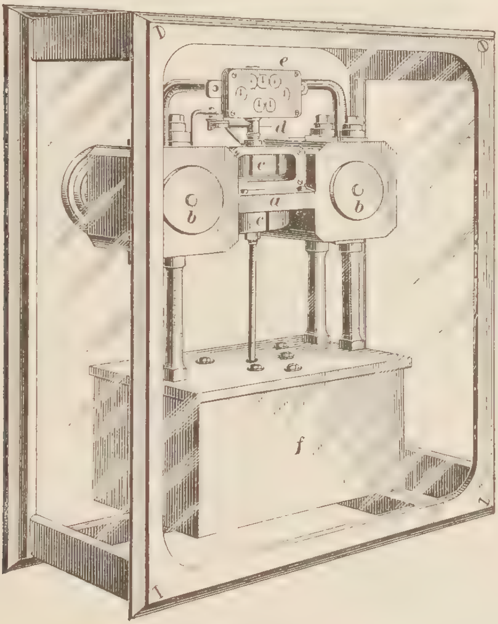


FIG. 1.

surrounding the heavy conductors on the back of the board affected the meter. In this meter any stray field affects both the armatures *c*, *c*, which are so connected that an outside field tends to turn them in opposite directions, and the disturbing effect is thus neutralized. The field set up by the instrument itself is in opposite directions on the upper and lower sides of *a*, so that these two fields propel the armatures in the same direction.

3. Car Wattmeter.—Recording wattmeters are also made in portable form for use in connection with railway work. They are very useful for making tests on the power consumption of cars. Fig. 2 shows a Thomson recording wattmeter as adapted for use on street cars. It is made so that it can stand considerable jarring without injury. It differs from the stationary types of Thomson meters in that an iron core *A* is used in the field. This gives a much

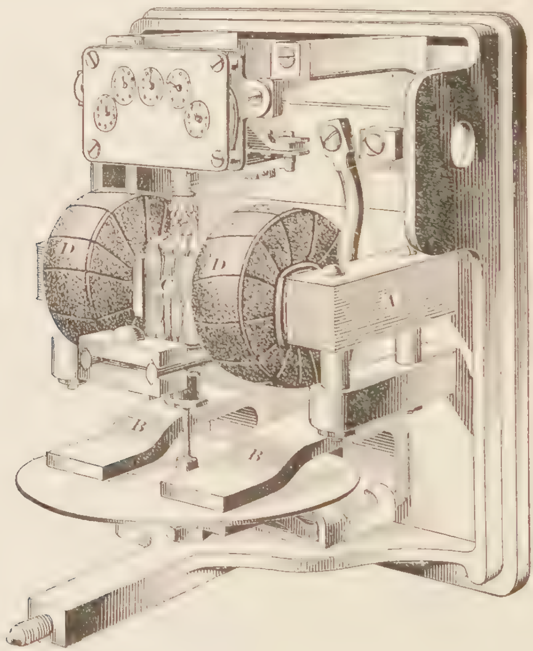


Fig. 2.

stronger field than where no iron is used, thus giving a larger twisting action on the armature, so that jarring is not so liable to interfere with the accuracy of the meter. *B*, *B* are the damping magnets used to control the speed and *C* is the armature. The current coils *D*, *D* are connected between the trolley and the motors so that the current used by the car passes through them. The armature *C*, in series with its resistance, is connected across the

line between the trolley and ground so that the current in it will be proportional to the voltage supplied to the car. The ordinary style of stationary wattmeter is not suitable for car testing, as the shocks and jars would soon knock it out of adjustment.

4. Bus-Bars. — Railway switchboards are always provided with at least two bus-bars, and in case the equalizer connections are run to the board, an additional bar is necessary. One of the bus-bars (the positive) is run across to the feeder panels and there connected to the various feeders through the necessary circuit-breakers. The positive leads from all the dynamos are connected, through the main switches, to this bar. The negative bus-bar is usually much shorter than the positive, and is connected to the cables running to the rails or other ground-return connections. In many cases the negative bus-bar is not as large as the positive, because connection is made to ground between the panels, and hence the bar does not have to carry the combined current from all the machines. The positive bar, on the other hand, has to carry all the current across to the feeder panels. The bus-bars are generally of flat copper bar and are supported a few inches from the back of the board by means of heavy brass castings, which also serve to carry the current into them. Fig. 3 shows one of the common methods of mounting the bars. Too much stress cannot be laid on the fact that bus-bars should have ample cross-section. It is very poor economy to install small bus-bars on any board. If the loss due to the resistance of the bus-bars were to be considered for a few hours or days only, it would be small enough to neglect, but when it is remembered that this loss is taking place year in and year out, it is no small matter. The cost of the power wasted in a small pair of bars will more than offset any slight saving in first cost that may be effected by the comparatively small weight of copper.

From 1,000 to 1,200 amperes per square inch of cross-section is a safe allowance. Bolted connections between

bars will, if carefully made, carry from 180 to 200 amperes per square inch of contact surface. If, for example, a bus-bar has to carry 6,000 amperes, its cross-section should be at least $\frac{6000}{1200} = 5$ square inches. The bar may be made of any dimensions that will give a cross-section of 5 square inches; generally, however, the bars are of flat, rectangular cross-section. In this case, for example, 5 in. × 1 in. would answer. When very large bars are needed, they are usually made of a number of comparatively thin bars with air spaces between. In any event, the dimensions should be so selected that connections may

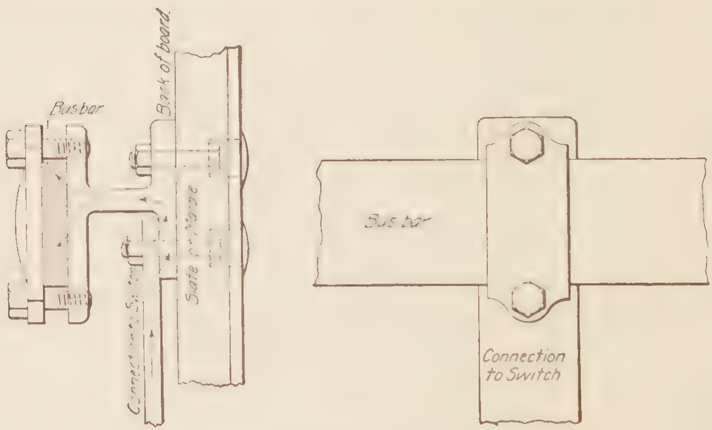


FIG. 3.

be made conveniently and give the required contact at the joints without lapping the bars too much. In the above case, a joint in the bar should have at least $\frac{6000}{200} = 30$ square inches surface, and the 5-inch bar should be lapped 6 inches. Great care should be taken to see that all joints on bus-bars or between the bus-bars and switches are well made and bolted tight. The current to be handled is large, and a poor contact, having what would, under ordinary circumstances, be called a very low resistance, may give rise to considerable local heating. If an equalizer bar is used, it is very essential that all its connections should be well made. A slight resistance at this point may interfere with the

proper working of the machines in multiple. If at any time the machines fail to work together as they should, examine all the connections through which the equalizing current has to flow, to see that none of them has become loose.

5. Lightning Arresters.—A lightning arrester designed for use on a railway circuit has to operate under especially severe conditions, because one side of the system is grounded, and whenever a discharge passes through the arrester a short circuit results; besides, the pressure on railway systems (500 to 600 volts) is comparatively high. A great many different types of air-gap arresters have been used and are in all cases provided with some device to extinguish the arc following the discharge. In the General Electric Company's arresters the arc is extinguished by a magnetic blow-out arrangement, very similar to that used on their circuit-breakers. In the Garton arresters the arc is formed in a confined space and drawn out until it is broken, the action being almost instantaneous. In one type of Westinghouse arrester the discharge leaps across charred grooves in a confined space between two lignum-vitæ blocks and is practically smothered out. All these arresters are used for railway work. Of course, no matter what type is used, it is liable to fail at times, and arresters should be used liberally out on the lines instead of depending altogether on the station arresters.

6. Westinghouse Tank Arrester.—Fig. 4 (*a*) and (*b*) shows a style of arrester that has been used extensively for railway stations. This device, which is known as the **tank arrester,** differs materially from the ordinary air-gap arresters. The object and action of the tank arrester is to ground through a water resistance that part of the circuit that is to be protected. The arrester is used only when there is danger from lightning, and during this time the line to be protected is in actual connection with the ground, so that a lightning discharge does not have to jump an air gap in order to get to the earth. An air-gap arrester requires an abnormal potential to force the

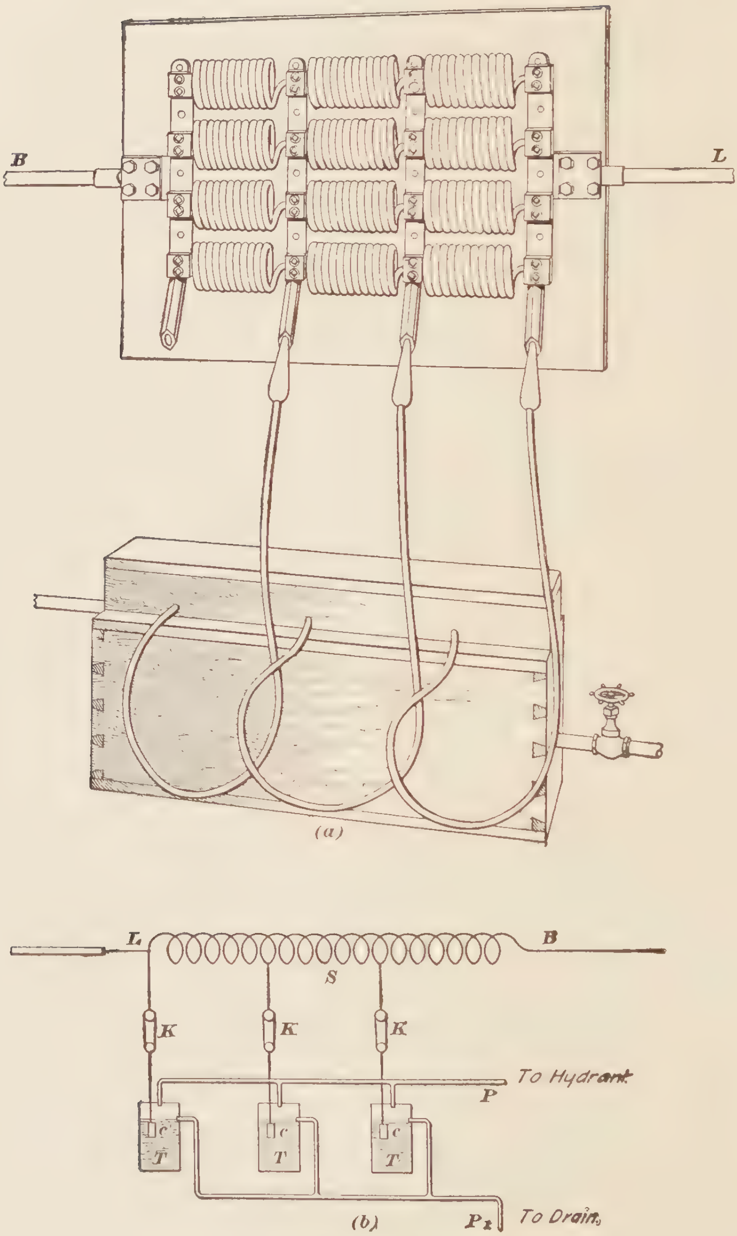


FIG. 4.

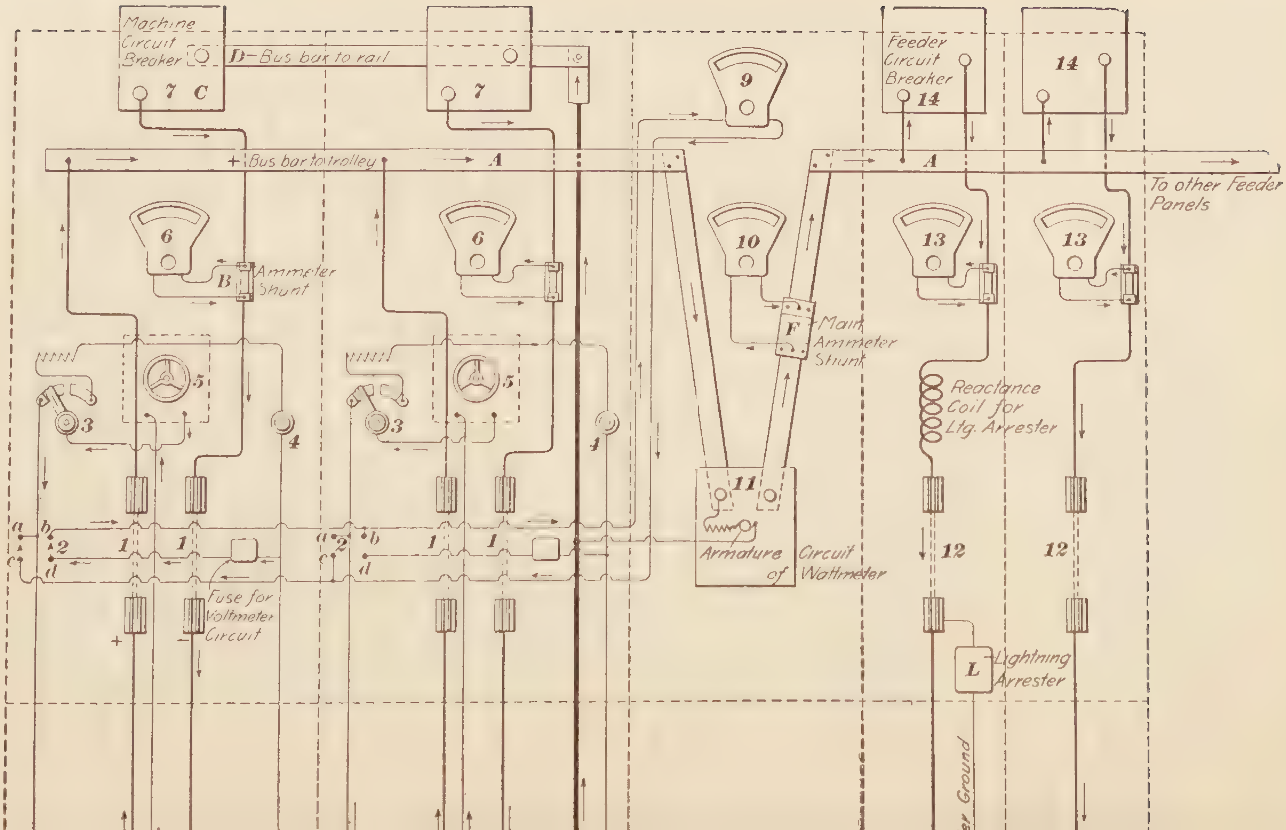
discharge across the gap; but the tank arrester works all the time and equalizes the line potential before it has a chance to reach a dangerous value. The strong point in favor of a tank arrester is that it passes off the induced charges due to overhanging clouds before they give rise to a line pressure high enough to cause a strike. The tank consists of three chambers *T*, *T*, *T* (*b*), each of which is kept filled with water by means of a stream that flows in at the same rate as it is allowed to flow out through an iron pipe to earth. Plunged into the water of each tank is a block of carbon *c* that connects directly to the device to be protected. The coil *S* shown in the figure constitutes a choke, or reactance, coil that makes the lightning pass through the arrester to ground in preference to going through the machine to ground. In Fig. 4 (*b*), the end *B* of the choke coil is connected to the + bus-bar and all on the station side of the choke coil is protected. *L* is the line or feeder over which the discharge of lightning is apt to come in. Plugs *K* connect the several sections of the choke coil to the several tanks in such a way that the choke-coil sections are all in series, and the tanks offer successively three different paths to earth, so that if a discharge misses the first tank, it still has the second and third tanks through which to reach the earth. The carbon plates are the positive pole of the arrester, the tanks and water the negative pole. It is thus seen that when the plugs are in place there is a direct connection from the line through the water to the ground. Current, therefore, flows through the arrester all the time it is connected, and for this reason it is only used when there is danger from storms. Of course, this arrester wastes a certain amount of current (about 3 amperes for each carbon in use), but it gives efficient protection, and the waste of current is a small item compared with the damage that might be done if the lightning discharges were not carried off.

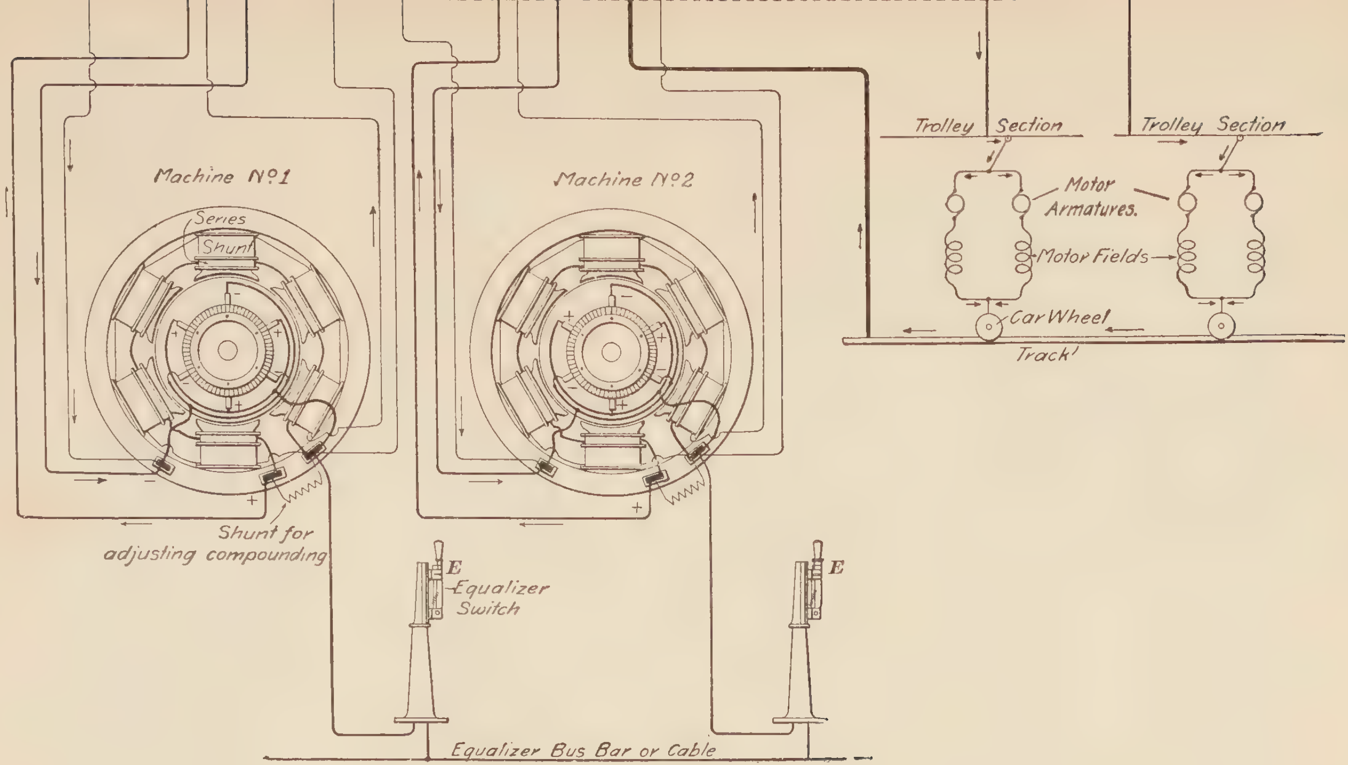
7. Where ordinary air-gap arresters are used, each feeder should be equipped with one. Sometimes these feeder

arresters are placed on the back of the board, but more often they are placed at a point near where the feeders enter the station and may be either inside or outside of the station. In addition, each generator is usually equipped with its own arrester, which is mounted on the back of the generator panel.

SWITCHBOARD CONNECTIONS.

8. The various devices that go to make up a railway switchboard have been considered, and we will now look at the connections necessary for an ordinary board. Of course, switchboards may differ considerably in their connections and yet accomplish the same purpose, so that it is not possible to lay down any fixed rules regarding them. Fig. 5 shows connections suitable for a board similar to the one shown in *Electric Railways*, Part 1. The various devices have been numbered to correspond in the two figures, and a number of minor fittings and connections have been omitted in order not to confuse the drawing; for example, connections are not shown for the switchboard or instrument lamps or for the exciting circuit of the Thomson ammeters; if Weston instruments were used, these latter connections would not be required. Only two feeder panels are shown, as the connections for all of them are alike. In this diagram the equalizer switch E is shown mounted on a stand near its machine, as this is the practice followed in the more recent plants. The + and − leads from the generators lead directly to the lower posts of the main switches. The upper posts of the + switches connect directly to the + bus-bar A. The upper posts of the − switches connect, through the ammeter shunt B and circuit-breaker C, to the − or rail bus-bar D. Note that the ammeter and circuit-breaker are not connected in the + side. This is because the equalizer is connected to the + side and the machine might be sending current through the equalizer, in which case the current in the + side on the switchboard


Machine
Circuit
Breaker
7 C
D–Bus bar to rail
7
9
Feeder
Circuit
Breaker
14
14
+ Bus bar to trolley
A
A
To other Feeder
Panels
6
6
B
Ammeter
Shunt
10
13
13
F
Main
Ammeter
Shunt
5
5
3
3
4
4
Reactance
Coil for
Ltg. Arrester
11
Armature
Circuit
of Wattmeter
a
b
c
d
2
1
1
a
b
c
d
2
1
1
12
12
Fuse for
Voltmeter
Circuit
+
–
L
Lightning
Arrester



Machine No. 1
Series
Shunt
Shunt for adjusting compounding
Machine No. 2
E
Equalizer Switch
E
Equalizer Bus Bar or Cable
Trolley Section
Trolley Section
Motor Armatures.
Motor Fields
Car Wheel
Track

FIG. 5.

would not be the total current delivered by the machine. Under such circumstances, an ammeter connected in the + side would not give true indications. Of course, the equalizer will work all right no matter whether the pole it is connected to is + or −, the only condition being that it must connect together the points where the brushes are connected to the series winding.

The + bus-bar *A A* is carried through the wattmeter as indicated at *11*, so that the whole current passes through *11* on its way to the feeder panels. The shunt *F* for the total-output ammeter *10* is also connected in series with *A* between the generator and feeder panels, so that *10* indicates the total current.

The voltmeter is connected to either machine by means of the plug receptacles *a*, *b*, *c*, *d*; *a* and *d* are in each case connected to their respective dynamo terminals, while *c* and *b* are connected to the voltmeter. When the plug is inserted, *a* is connected to *c* and *b* to *d*, thus giving a reading. Note that a voltmeter reading may be obtained even if the main switches are open; this is essential, because the voltage of a machine must be adjusted before it is thrown in parallel with another.

On the feeder panels, the circuit-breaker, ammeter shunt, and feeder switch are simply connected in series. If a lightning arrester is used, as indicated on one panel at *L*, the connection between the ammeter shunt and the feeder switch is usually coiled up, as shown, in order to form a reactance, or choke, coil to help keep the lightning discharge out of the machines.

SPECIAL ELECTRICAL APPLIANCES.

9. In describing the foregoing apparatus required for the power station, we have considered only that to be found in the ordinary station operating at 500 volts and supplying the current direct from the machines to the various parts of the system. On some roads, however, special conditions

arise where one or more of the feeders have to run to points much farther distant from the station than others. Almost every power station has several feeders running from the bus-bars out to different sections of the trolley wire. Some of these feeders will be short and there will not be very much drop in them; others will be long and the line loss in them may be so great as to seriously interfere with the operation of the cars on the distant sections of the road. Of course, the voltage of the bus-bars in the power station could be raised by raising the voltage of all the dynamos that feed into them, but this would also raise the voltage on the short feeders that do not require a high voltage. In order to supply a high voltage to those feeders that require it, a number of different schemes are used.

10. Use of Auxiliary Bus-Bar.—Fig. 6 shows one method that is available when one of the machines in the station can be set apart for the supply of these high-voltage feeders. It consists simply in supplying the feeder boards

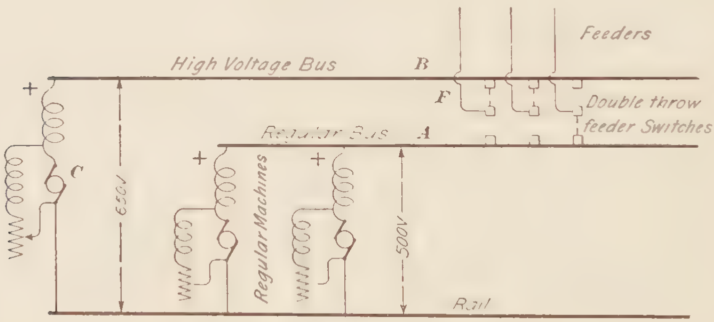


FIG. 6.

with an additional bus-bar B, which is connected to machine C. This machine, for example, might generate 650 volts, while the regular machines feeding into + bus-bar A generate the usual 500 volts. The feeders are connected to double-throw switches F, so that they may be run on either the high or low bus; hence, if any feeder is heavily loaded or if it runs to an outlying point, it may

be connected to the high-voltage machine *C* by throwing its switch up; at the same time the other feeders would be supplied from *A* at the usual voltage.

USE OF BOOSTERS.

11. A separate machine is not always available for use, as described in the last article, in which case a **booster** is generally employed to raise the voltage for those feeders that require it. The term booster is used in railway work for a number of different appliances. It is used to designate a machine to raise the voltage on outgoing feeders, and it is also used in reference to the machine for regulating the charge and discharge of storage batteries. In all cases, however, the term booster carries with it the idea of a machine for changing voltage, and we shall now consider only the type of machine used to increase the voltage supplied to outgoing feeders; the storage-battery booster will be taken up later.

12. Let us take the case of a single large dynamo feeding into a pair of street-railway bus-bars from which run out a long feeder and a short one, as shown in Fig. 7. In this figure, *A* represents the power-house dynamo feeding into the two bus-bars *a b* and *c d*. Running out from the positive bus-bar *a b* are two feeders *e* and *f* that supply the two sections of trolley wire *C* and *D*, respectively. *M* is a car somewhere out on the line. Feeder *e* is so short that no excessive drop in voltage takes place through it, so that it does not require an increased voltage; but feeder *f*, being much longer, does. In order to supply the additional voltage, the armature of a dynamo *B* is connected in series with the feeder *f*. Any kind of dynamo can be used as a booster, but some dynamos are much better adapted to this service than others. The series dynamo is used most largely for this work in railway plants, because, between certain limits of load, its ability to add voltage to the circuit increases directly as the demand made upon it. In other words, all

the current that goes through the feeder passes also through the series field of the booster and enables it to generate voltage in proportion. It is easy to see, then, that since the booster must carry the entire load of the feeder or feeders with which it is in series, its current capacity must be equal to the entire current required by the cars that run on the trolley sections fed by the feeder or feeders connected to the booster. Although the current capacity thus has to be large, the voltage generated by the booster is usually only a fraction of that generated by the main dynamo, so that the *watts* output of the booster may be considerably less than that of the main dynamo. In many instances, special switches have been provided, so that one of the regular 500-volt dynamos, running ordinarily as a dynamo in multiple

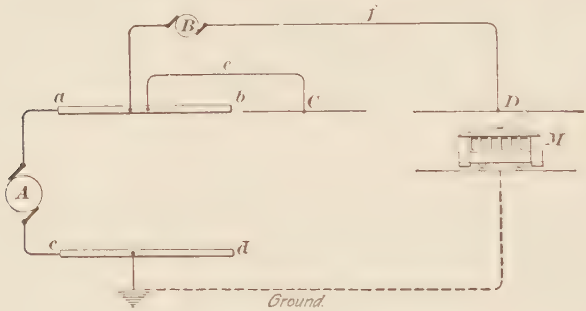


FIG. 7.

on the bus-bars with the other dynamos in the station, can be cut out of the regular dynamo service and cut into series with one of the feeders as a booster. Where a dynamo can always be spared for such service, such an arrangement saves the expense of buying a special machine for the work. It is rarely the case, though, that a feeder requires to be boosted as much as 500 volts. The number of cars supplied by the feeder may call for the full current-carrying capacity of the available 500-volt compound-wound dynamo, but need not call for its full voltage. In such a case, it is the custom either to cut out the shunt field on the dynamo and resort to the series field alone or to use some special method of

separately exciting the shunt field to any desired degree and supplement its field with that due to the series coils. It is easily seen that a dynamo that is run at normal current, but under the normal voltage, is not running at full load, and is not, therefore, running with the greatest attainable economy. The question of connections for a *convertible booster and dynamo* will be taken up later.

13. Boosters for use in railway service can be bought specially wound to handle any current at any voltage to suit the conditions of the particular service to which they are to be put. Such machines are usually designed to run from a steam engine direct-connected or from a motor whose armature is coupled to the same shaft and whose bedplate supports the frame of both machines. The booster plant can be installed in the power station itself or it can be put out on the line. On account of the cost of attendance, the power station is the best place for it, unless there are conditions that prohibit its being placed there. Where each feeder supplies its own section of trolley wire, as shown in Fig. 7, it makes no difference where the booster is located so long as it is in series with the feeder, because the booster can never be called on to carry any current except what goes to section *D*. But on such feeder construction as that shown in Fig. 8, it makes a great difference, especially to the

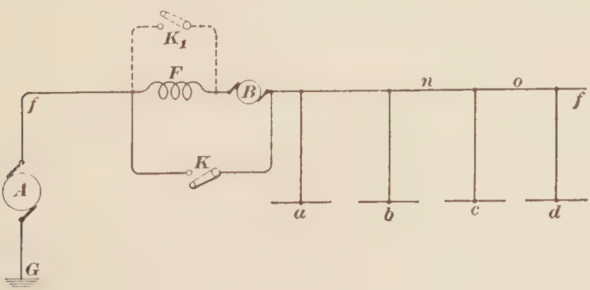


FIG. 8.

booster itself, where it is placed. In Fig. 8, several sections of trolley wire *a*, *b*, *c*, *d* are connected to the same feeder *f f*. If the booster is cut in at *B*, it must carry the current

called for on all four sections; if it is cut in at *n*, it will carry the current for the *c* and *d* sections only; while if it is cut in at *o*, it will have to carry only the current that goes to section *d*; so that a booster put into a feeder at *B* would have to have four times the current-carrying capacity of one put in at *o*. Most feeder work at the present time is laid out after the plan shown in Fig. 7, so that the booster can be placed in the power station as well as not.

14. Operation of an Engine-Driven Booster.—The same rules that are observed in the care and operation of a dynamo of any other kind hold good in the case of the booster; but on account of its unusual relationship (being in series) to the rest of the circuit, it has some peculiar points not found where dynamos are run in multiple. In the first place, great care must be taken to connect the machine properly, so that it will add its voltage to that of the power house. The polarity of the booster may be determined by means of a voltmeter, as this is the most convenient method. We will suppose that the booster, which is a series machine, is not connected in circuit, but is running at about half speed. Short-circuit its terminals with a piece of light fuse wire, so that it may be able to generate and at the same time note the direction in which the needle of a voltmeter attached to the terminals deflects. The negative terminal of the booster must connect to the power-house end of the feeder and its positive terminal to the line side of the feeder; for it must be borne in mind that connecting the booster in series with the feeder is really connecting it in series with the dynamos that supply the power-house bus-bars, from which the feeder draws its current, so the positive side of the generator must go to the negative side of the booster. After the circuit is once closed by connecting in the booster, the line current dictates the polarity of the booster voltage, so this polarity cannot be wrong, unless the machine itself is incorrectly connected. Since for given connections, the booster, like any other dynamo, can generate only for one direction of rotation, it follows that if the

direction of rotation proves to be such that the machine cannot be made to generate even on short circuit through the light fuse wire, either the field or armature terminals must be reversed or the booster must be turned end for end so that the direction of rotation of the armature may be reversed. If the booster is direct-connected to the engine, turning it end for end is of course impracticable, so that it is best to reverse the connections of the field or armature. If the booster is direct-connected to a motor, the best plan is to reverse the shunt field on the motor.

Reverting to the engine-driven booster: since the booster is a series machine and since series machines run in the opposite direction as motors from what they do as dynamos, the connections remaining the same in both cases, the effect of throwing the booster into service with either its field or armature leads crossed would cause it to keep on running in the same direction as a motor, with the result that, instead of boosting the voltage of the feeder, it would insert in the circuit a counter E. M. F., the amount of which would depend on the value of the current in the feeder; in this case, the voltage in the feeder would be made less instead of greater. The next mistake possible is, after getting the fields and armature of the machine properly connected, so that the machine can act as a dynamo, to get the dynamo as a whole cut into the feeder electrically wrong end to, so that its polarity opposes that of the dynamo supplying the feeder.

15. Cutting the Booster In and Out.—The principle involved in cutting a booster in and out of service is very much the same as that used to cut in and out arc-light dynamos that run in series on the same load. As a matter of fact, the feeder, or the dynamo that supplies it, and the booster are just as much in series as are two arc-light dynamos on a lamp load. In Fig. 8, B and F are the armature and field, respectively, of the booster connected in series with the feeder at the power house and driven by a steam engine not shown. K is a switch across the outside

terminals of the booster and K_1 is a switch across the terminals of its field. There are several ways of rendering a booster electrically inactive. One way is to short-circuit its field by means of a switch connected across it, as shown at K_1. In this case, the armature continues to carry the same amount of current as the feeder, but even if the booster engine is kept turning at full speed, the pressure of the feeder current is not raised any, because, since the field is cut out, no voltage is generated within the armature itself.

Another way to cut the booster out of active service is to simply short-circuit the field and shut the steam engine down; in this case, the feeder current continues to pass through the armature of the booster, and to avoid unnecessary drop and heating, it is well to provide a switch such as K, so that the whole machine can be cut out *after* it is shut

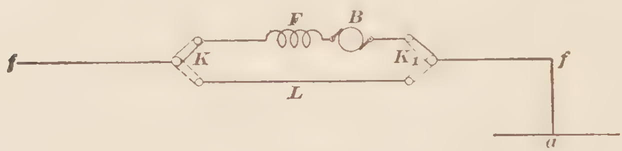


FIG 9.

down. Under no circumstances should the switch K be closed while the booster is up to speed, for, since the machine is connected to generate, the effect would be to have it act as a dynamo on short circuit through the local path K–F–B–K. Nor should the engine be started up with K closed unless K_1 is closed also, because the same thing will happen.

The safest arrangement of all is to install a combination switch that will open the booster circuit at both ends and put a bar of copper in its place to close the circuit. Such a switch is shown in the sketch in Fig. 9, where f f is the feeder; a, the trolley section that it feeds; F B is the booster; and L is the bar of copper. K and K_1 are two double-throw switches, shown at opposite ends of the booster in the diagram, but in practice they are mounted on the same base plate and operated by the same handle. When the switch blades are in the full line position, as shown in the

figure, the booster is in service; but when the switch blades are thrown down to the dotted position, the booster is cut out at both ends and the copper bar L takes its place. This method has the advantage that the machine is entirely cut out and *dead*, as it is termed.

16. Motor-Driven Booster.—When a motor is used to drive the booster, the shunt-wound type of motor is invariably selected, because it runs at practically constant speed no matter what the load on it may be. As far as the booster itself is concerned, it does not matter whether it is driven by a motor, a waterwheel, or an engine as long as the speed is kept up so that it can provide an E. M. F. proportional to the current demand on the feeder. On the other hand, the use of a motor for driving widens the field for electrical troubles in so far as the motor takes the place of the steam engine. Especially is this the case where the booster unit must be placed out on the line. In either case,

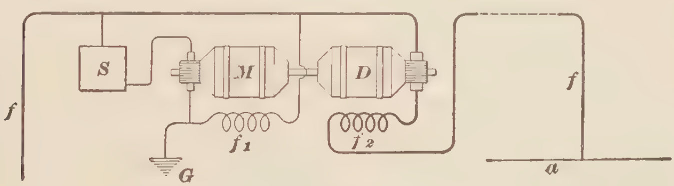


FIG. 10.

whether the booster is in the power house or out on the line, the motor is connected in the same way as any other shunt motor; that is, there must be facilities for starting and stopping it and also for protecting it in case there is trouble on the line. As shown in Fig. 10, the booster as a whole is put in series with the feeder, and the motor as a whole is put across the line, i. e., between the trolley and ground. In this figure, M is the motor armature, which has the starting box S in series with it; f_1 is the shunt field of the motor; $f\,f$ is the feeder supplying trolley section a; D is the booster armature; f_2 is the series field, and G is the ground or rail return. If the booster unit is out on the line, it is not difficult to see

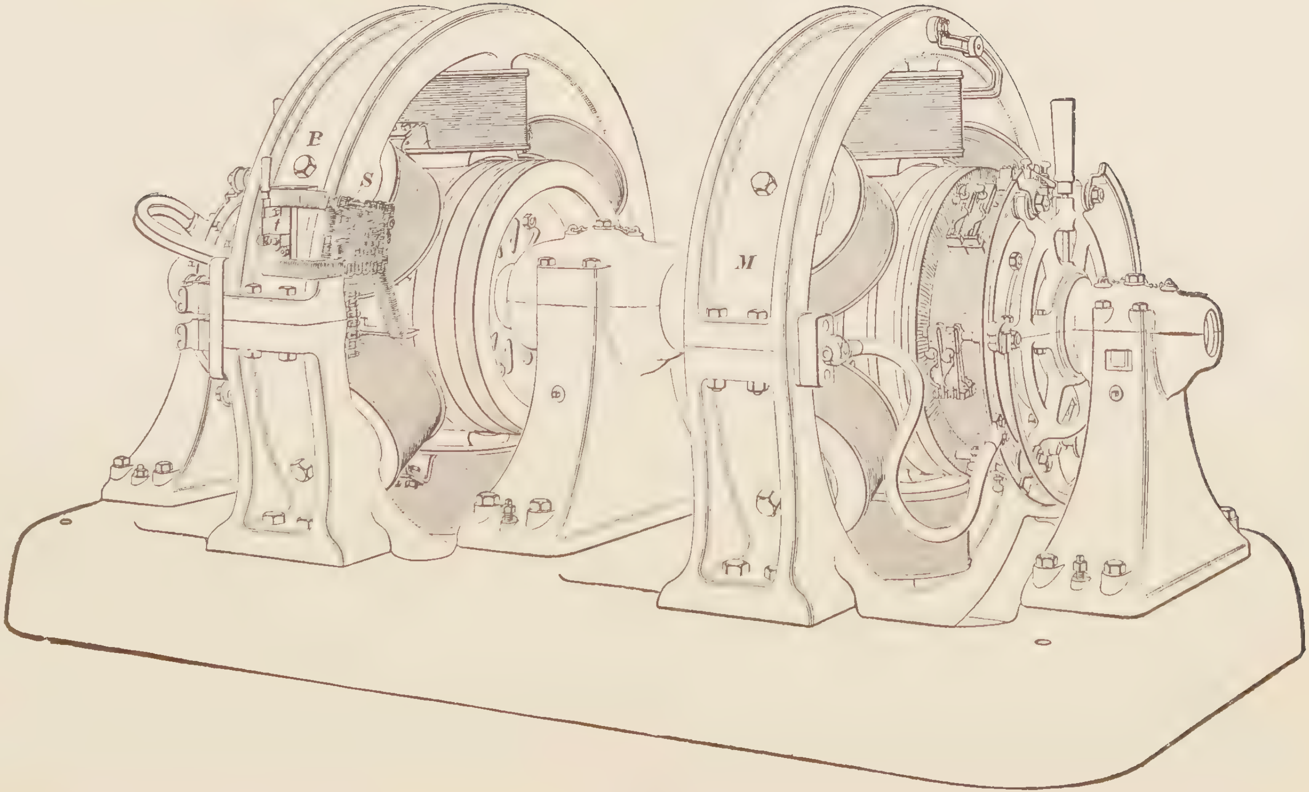


FIG. 11.

that trouble might be brought on some time by the power going off the line, in which case the motor would stop, as there would be no power to run it. Then, when the power comes on again, the motor being across the line, produces a prolonged short circuit. There would be an abnormal flow of current through the armature because the motor would be standing still and generating no counter E. M. F. On this account, when the booster is put in a place removed from the power house, it must either have attendance all the time or it must be provided with very refined devices for starting and stopping it in time of trouble.

As a rule, though, in present practice, if a single feeder is to be boosted and the additional E. M. F. required is not too great, the boosting is done by putting one of the regular dynamos, compounded to a high degree, on the feeder. It is sometimes the custom to put the booster in series with several feeders which run out about the same distance from the power house or whose load demands are, for other reasons, about the same, in which case the booster cannot be put out on the line, but must be put in the power house, where it can be cut in at a point common to all the feeders to be boosted. When the booster is installed in the power house, the fields of the motor are excited from the station bus-bars, and, as a rule, the motor armature is operated from that source. The booster field and armature are, as usual, put in series with the feeder or feeders to be boosted. Fig. 11 shows a type of motor-driven booster made by the General Electric Company. There are two separate armatures, each of which has its own frame and pole piece, but the two frames are mounted on the same bedplate. M is the shunt-wound motor driving the series booster B; S is a shunt across the field of the booster, which can be cut in or out of service by means of switch t.

17. Convertible Booster.—As previously mentioned, it sometimes becomes desirable to adapt one of the regular station dynamos to booster use. In such a case, provision is made so that the machine can be used either as a dynamo

in the regular service or as a booster to raise the voltage on a feeder or group of feeders.

In Fig. 12, L is the power-station dynamo; its positive terminal goes to the positive bus-bar, marked + in the figure. The negative terminal of the dynamo connects to the negative bus-bar; and the junction of the dynamo series field and brush holder is connected to the equalizer bus-bar, used only when more than one dynamo is carrying

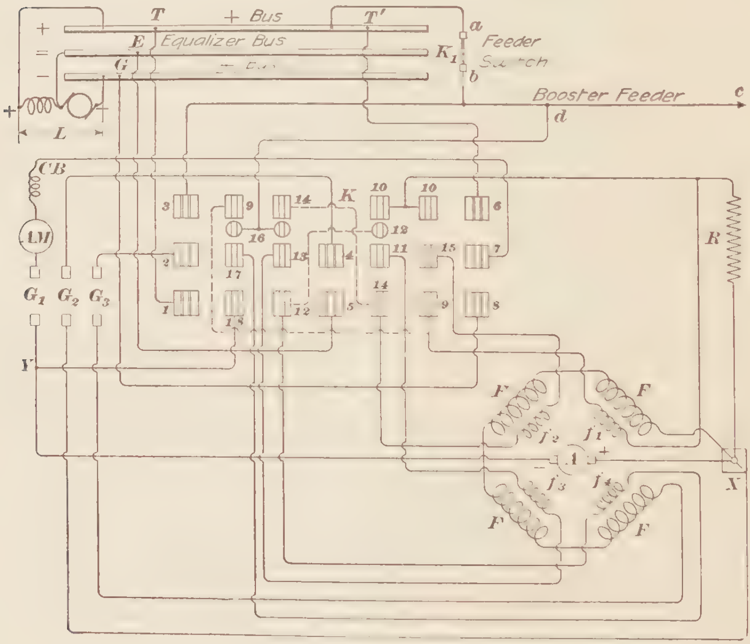


FIG. 12.

the load. In the lower right-hand corner of the figure the booster is shown. F, F, F, F are the series coils of the booster and f_1, f_2, f_3, f_4 are the shunt-field coils. The circle A in the center is the booster armature. G_1 G_2 G_3 is the generator switch. The switch K, with the numbered blocks, is used for connecting the machine either as a booster in series with the booster feeder or as a dynamo in multiple

with dynamo L or whatever other dynamos may be carrying the load. When the switch K is thrown up, the machine acts as a booster, but before it can do so the feeder switch K_1, which short-circuits it, must be opened. When switch K is thrown up, block *2* connects to block *3*; block *7* to *6*; blocks *9*, *14*, *16*, *17*, and *13* connect together; blocks *10*, *11*, *12*, and *15* connect together. It will be noticed that the series coils of the machine are all connected in series, the same as on any dynamo or motor; each shunt coil, however, has a pair of leads of its own, because when the machine is used as a booster, all the shunt coils must be in multiple, and when the machine is used as an ordinary dynamo, all the shunt coils must be in series as usual. The two ends of the booster circuit are T' and b; the two ends of the switch K_1 are a and b; points T' and a are practically the same point, being connected by a few feet of stout copper bus-bar. It is easily seen, then, that if switch K_1 is closed, the two ends of the booster circuit are brought directly together; in other words, the machine is short-circuited. When the switch K_1 is open, however, the only way that current from the positive bus-bar can get out on the line to the cars by way of feeder $b\ c$ is to go through the booster, which, if its polarity is right, adds its voltage to that of the line dynamos. Neglecting for the present the shunt field of the booster and assuming that switch K_1 is open, the path of the current through the power-station dynamo, the booster, and the booster feeder is $L+\ -T-T'-6-7-C\ B$ (circuit-breaker) $-A\ M$ (ammeter) $-G_1-A-\ -A+\ -X-F-F-F-F-G_3-$ $2-3-c$ through the cars, back to the station by way of the rail to the negative side of L. When the switch K_1 is closed, the path of the current is $L+\ -T-T'-a-K_1-b-c$, and so on, the booster being cut out. The booster field is excited not only by the series coils, but also by the shunt coils, which are all in multiple, thereby greatly decreasing the resistance of the shunt-field circuit, so that it may be excited by being connected in parallel with a certain length of the feeder, and thereby subjected to the voltage drop in that length. One end of the f_1 shunt-field coil goes to block *9* and the other

to block *10*. The ends of field coil f_2 go to blocks *14* and *15*; the ends of f_3 to blocks *11* and *13*; the ends of f_4 to blocks *17* and *12*. The result of this arrangement is that when the booster switch is thrown up, the positive ends of all the shunt coils go to one set of blocks that are connected together and the negative ends to another set of blocks that are also connected together. The positive ends go to blocks *10*, *11*, *12*, and *15*, which are all connected together by the switch blade when the switch is thrown up. The negative ends go to blocks *9*, *13*, *14*, and *17*. Double block *16* connects to the feeder at some point d, determined by the amount of feeder required to give the drop necessary to excite the fields sufficiently. Double block *16* connects to the negative ends of the fields when K is thrown up. Double block *10* connects to the positive ends of the fields when K is thrown up. The connecting wire from double block *10* leads through the field rheostat R and the block X to the positive side of the booster armature.

18. When the booster switch K is thrown down, blocks *2* and *1* are connected together; block *17* is connected to block *18*; block *13* to block *12*; *4* to *5*; *11* to *14*; *15* to *9*; *7* to *8*. In both positions of the switch, the large blocks are connected with the main booster circuit and the small blocks with the shunt-field coils. The two ends of the booster, which is now connected across the trolley and ground bus-bars as a regular generator, are T and G; the path of the booster current is $A+-X-F-F-F-F-G_3-2-1-T$, out on the line by way of the switch K_1 and the feeder c to the cars, through the motors to the rail, along the rail back to the ground bus-bar G in the power house, through $8-7-C\ B-A\ M-G_1-A-$. The current contributed by the booster joins the current contributed by the station dynamo L at point T. One end of the shunt-field circuit is at block X; the other end is spliced to the negative armature wire $A--G_1$ at Y, and the path of the current through the shunt field is $A+-X-R-f_1-9-15-f_2-14-11-f_3-13-12-f_4-17-18-Y$. The shunt coils are now all in series and the

current flows through them in the same direction that it flows through the series-field coils.

19. Economy of the Booster.—The booster may be regarded as an electrical economizer, not in the same sense of the term that holds good when applied to such devices as a condenser for exhaust steam or the heater for feed-water used in a steam plant, because these devices effect a still further economy under conditions that are already comparatively good, but in the sense that at times it may relieve a hopeless condition that nothing else will without great cost.

Suppose, for example, that a certain section of a road is a long distance from the power house and operating with a large drop. The voltage at the cars will be low and they will run slowly. If a booster is installed, the voltage at the cars will be raised and they will run faster. The result will be that, while the current they draw from the power house may be nearly as large as it was before, because the series motor such as used on street cars takes a certain current for a given effort no matter what the speed may be, the cars will not require the current for so long a time; hence, more cars may be operated. The booster, therefore, actually increases the working efficiency of the system and improves a condition that could not be otherwise bettered without a very large expenditure for copper in the overhead feeders.

The booster, of course, requires power for its operation. This fact becomes more apparent when the booster is put out on the line and a motor used to run it; in this case, there is not only a loss within the booster itself, but there is an additional loss in transmission, because the booster motor draws current from the line at low pressure and gives it back to the feeder at high pressure, but the generator end of the booster can never give back to the line as much energy as the motor end takes out of it. The service rendered by the booster, however, cannot always be estimated by the amount of energy that it consumes. There are conditions under which no other means outside of a substation or a new

power house will make the car service practicable. The feeder to be boosted may be so long as to render the addition of enough copper out of the question. On account of low voltage, and hence low car speed and unsatisfactory service in general, the public will refrain from riding on that part of the line except when they cannot help themselves. The addition of a booster will enable the cars to run on time and draw the travel. It is a well-known fact among street-railway men that for a given time table, low voltage on the line is much harder on the motors and controllers than high voltage, because, in the first place, the motorman must get his quick start by throwing the controller far around before the car has run any distance; and, in the second place, each car, instead of coasting, has to take current in order to make its time.

STORAGE BATTERIES IN CONNECTION WITH ELECTRIC RAILWAYS.

20. Storage Batteries on Cars.—The storage battery as applied directly to the running of cars and stationed on the cars themselves has not, for several reasons, scored the degree of success that it has attained in other lines of work, the main feature militating against the direct application of storage batteries being their excessive weight. One of the storage-battery traction systems that has most nearly approached success in America is that installed on the system now known as the Chicago Electric Traction Company. It is a fact beyond dispute that the overhead-trolley system is far more economical than the storage-battery system, and the Chicago advocates of the latter system do not claim otherwise, but they state that on their own line, where the erection of overhead work was not allowed by the city, the storage system has been operated on a profitable basis. They operate about 25 cars over a line 30 miles long, and for these 25 cars 40 batteries are provided. Each battery is composed of 72 cells and weighs, with its tray,

about 3 tons. The motors are mounted on the outside of the axles, leaving the space between the axles for the tray of batteries. The weight of the batteries renders their handling a problem that has been very successfully and economically worked out by providing an automatic shifter, which does away with manual labor entirely in effecting a change of batteries. All connections are made automatically by means of spring contacts

Each storage cell when fully charged gives an E. M. F. of 2.18 volts, so that 72 cells would furnish a voltage of $72 \times 2.18 = 157$ volts. Each car is provided with a single 50-horsepower motor wound for 135 volts, so the motor is subjected to an excess pressure of 22 volts, but seems to be in no way harmed by it. It is a well-known fact that the E. M. F. of a storage battery becomes less as the charge is paid out. In the case in question, the batteries are charged until their E. M. F. is 2.18 volts per cell and are allowed to run until the E. M. F. falls to 2 volts. During this drop in E. M. F., the car makes from 10 to 12 miles. The batteries would run the car farther than this, but experience has shown that this is the most economical run to get out of the car before recharging. As far as the actual running life of the batteries is concerned, this is limited only by the disintegration of the positive plates. The old-time weakness of buckling does not give any trouble on this road, but it is found to be a great advantage to thoroughly wash and clean the plates after the completion of each 4,000 miles. If the car averages 100 miles a day, this would mean a cleaning of the plates every 40 days, or, say, every month and a half.

In charging the batteries, a current of 160 volts pressure is first applied; as the charge increases and the E. M. F. of the battery rises, the charging voltage is raised to 170, and finally to 180 volts. The motors used on such a system as this must, of course, be especially designed for the lower voltage and the larger current. A 50-horsepower motor to be run on a 135-volt line calls for a current of $\frac{50 \times 746}{135} = 276$ amperes

—a current which, if it had to be transmitted to a distance for any number of cars, would cause a prohibitive line loss. In this case there is no line, and therefore no line loss, and on account of the low voltage, insulation breakdowns are very rare.

21. One of the most valuable features of the storage battery is its ability to deliver heavy currents for short intervals. It is therefore very valuable as an auxiliary in power plants or substations to steady the load carried by the dynamos or rotary converters. In almost all power houses there are certain times of the day when the dynamos are called upon to run at their full capacity in order to carry the load. At other times of the day, when the traffic is light, there may be very little demand on the dynamos and perhaps only half of them may be in use. The average load on the power house has a certain value, but the maximum load may be easily twice this value. It is easily seen, then, that while the machine capacity of the power house should be adequate to meet only the requirements of the average load in order to fulfil the best possible conditions of economy, yet, in order to meet the actual requirements of the service, it is necessary that the machine capacity of the power house should be able to cope with the maximum load; otherwise, just when it is most urgent that the cars should run on schedule time, the station will not be able to supply enough power.

In a small power house it is usually necessary that the machine capacity should be adequate to meet the demands of the maximum load. But in such a case, the actual amount of machine capacity represented by the difference between the maximum and average load is small compared to the difference between that of a large power house, and so does not amount to as much from a money point of view. In a large power house the difference between the maximum and average loads may amount to several thousand horsepower, and this represents a very heavy investment in the way of machinery that may be idle a great part of the time.

22. Methods of Using Storage Batteries.—One way of expressing the fact that the storage battery helps out the power-station dynamos during their period of heaviest load is to say that the battery takes the **peak** of the load. The method of carrying this out is about as follows: The storage battery as a whole is put in multiple with the dynamos, being connected to the same bus-bars; during the hours when the load is light, the dynamos not only supply the outside load, but they charge the battery as well. When the rush hours come on, the battery helps the dynamos on the outside load. In this way the engines and dynamos are kept more nearly at full load all the time.

Storage batteries may be installed either as an aid to the power-house dynamos, by taking the peak of the load and cushioning the violence of the fluctuations, or they may be placed at the end of a long line to keep up the voltage and obviate the heavy line loss incidental to supplying large currents from the power house through long feeders. In either case, the final effect is to relieve the power house of some of its load.

23. Battery Used to Take Peak of Load.—An example of this application is found in the storage-battery plant of the Buffalo Street Railway Company. The storage batteries are installed at the main power house for the purpose of cushioning the fluctuations and to carry the peak of the load. Now, the generators in such a station are heavily overcompounded, and their terminal voltage, therefore, varies according to the load; the battery is in multiple with the generators on the bus-bars. Also, since the E. M. F. of the generators increases as the load increases and since the E. M. F. of the battery decreases as the load increases, on account of its internal resistance, there must be some means provided for regulating the voltage of the battery to suit that of the bus-bars. This regulation is effected by means of a motor-driven booster connected in series with the battery.

This booster is designed to increase the effective voltage

of the battery at the same rate as the load increases, thereby preserving the relationship between its E. M. F. and that of the generators. The positive end of the battery is connected to the positive bus-bar of the station; the negative end of the battery goes to one terminal of the booster armature, the other end of which goes to the ground. The motor end of the booster unit is a six-pole machine running at 500 revolutions per minute from the station bus-bars. The booster performs two duties: it regulates the voltage at which the battery discharges and it also helps to charge the battery. On this account, means must be provided for not only varying the voltage of the booster from zero to a maximum, but for reversing its polarity, because during a charge the current flows towards the battery, and during a discharge from it. This is done by means of a combination switch whose blade has three positions. In one of the positions, the polarity of the booster is such as to charge the battery; in a second position, the polarity is such as to discharge the battery; while in a third or neutral position, it is out of action.

The Buffalo road obtains its power from Niagara Falls as a three-phase alternating current, which is changed by means of rotary converters into a direct current for use on the railway. At night the rotary converters are used to charge the battery that is cut in on the line about 5.30 A. M. The battery itself is composed of 270 chloride cells, which at 2.18 volts each give a total of $270 \times 2.18 = 589$ volts. The battery has a capacity of 1,200 horsepower-hours, when discharged at the rate of 1,200 horsepower, in which case it would discharge in 1 hour. The cells are not full of plates, room being left for a future increase in the capacity to 2,000 horsepower at 1 hour's discharge. The containing tanks are made of wood, lined with lead, and are supported on porcelain insulators. The floor is made of concrete and slopes to one side to facilitate drainage. Insulating mats of wood are laid in the aisles between the rows of cells.

24. Battery Out on the Line.—An example of the second method of applying storage batteries to railway

work is found on the South Side Elevated Road, of Chicago. The cars operated are quite heavy, and the power station is near the center of the road. There are two storage-battery plants, one near each end of the line. The trains are all equipped with the Sprague multiple-unit system. This system provides that each car in the train shall be a motor car and that all the motor cars can be operated simultaneously from either end of any car in the train. On starting, the train accelerates very rapidly, and in a few seconds is under full headway, so that during this time the flow of current is large and the strain on the feeders severe. The load units being large, the fluctuations in the load are of course violent. The storage batteries are connected directly across the line without the intervention of any booster, and they depend for automatic regulation on the variation in the drop that takes place in the feeders between them and the power house. The drop varies between 10 and 30 volts, according to the load. When the load is light, the drop is small, and the voltage of the feeder, being above that of the battery, sends a charging current through it. The battery consists of 248 cells, having a capacity of 1,000 horsepower at the 1-hour rate. When the load is heavy, the excessive drop brings the feeder voltage down below that of the battery, enabling the latter to send a current into the line, thereby aiding the power house. The automatic regulation of the charge and discharge of the battery requires that there be a certain amount of variation in drop. If it is found that a battery is called on to discharge more than it is charged, an extra feeder must be run between it and the power house to raise the feeder voltage in the neighborhood of the battery and thereby relieve the battery of some of the load. In the battery plants of the above-mentioned road, each battery is connected to the power house through two special feeders, so that by means of them the automatic regulation can be helped. If it is found that the battery does but little discharging, it means that its E. M. F. relative to that of the feeder must be raised. This can be done either by putting several more cells in series with the

battery or by increasing the drop in the feeder itself. To do this, if there are extra feeders between the battery and the power house, as in the above case, one of them can be cut out. A battery used at the end of the line has the advantage of maintaining the voltage and enabling the cars to keep their schedule, besides relieving the generating apparatus and saving copper in the line. A drop of 10 per cent. in the lines is sufficient to allow the battery to operate automatically as above described. Of course, in all cases the line must be long enough and the load sufficiently heavy to justify the use of the battery; otherwise, no economy will be effected by its use.

25. Differential Storage-Battery Booster.—The action and use of the differential battery booster has already been explained. In this style of booster the whole output of the plant is carried through the series-field winding, and the battery charges and discharges according as the load on the line is light or heavy. This style of booster is generally used when the load on the line is rapidly fluctuating.

26. Compound Booster.—In cases where the battery is intended to take the peak of the load, which may extend over a considerable period, the compound booster is frequently used. This differs from the differential booster in that only the battery current passes through the series coils of the booster, as indicated in Fig. 13. A is the armature of the booster and F its series-field winding. G is one of the regular compound-wound generators feeding into the bus-bars; s, r, s', r' are the shunt fields and rheostats of the booster and generator. In this scheme of connections, it is seen that only the current furnished by the battery passes through F, and not the whole line current, as in the case of the differential booster. When the battery is carrying the peak of the load, the voltage across its terminals of course falls off as the current increases, on account of the internal resistance and also on account of the drop in voltage due to the cells becoming discharged. The booster voltage increases as the current delivered by the battery increases, and as this

voltage is added to that of the battery, the result is that the voltage at the bus-bars is maintained and the battery takes its share of the load. When the battery is to be charged, the polarity of the booster may be reversed by means of field reversing switches and the booster made to generate a voltage of the opposite polarity, thus helping the generator to

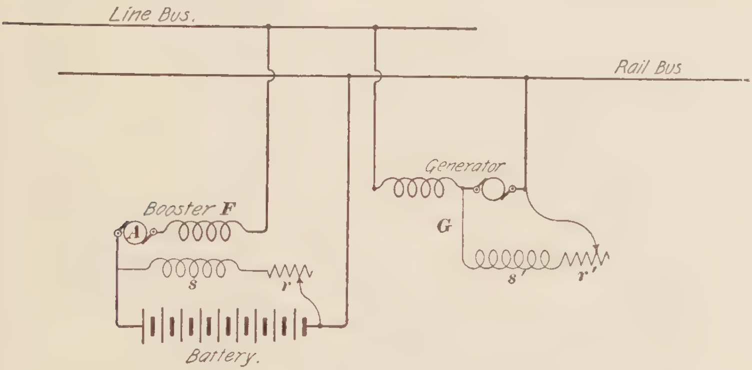


FIG. 13.

force current through the batteries. A booster of this type is used therefore when a battery is either to charge or discharge for a certain length of time, but where it has to discharge for short intervals and then charge for similar intervals, as it should on a load subject to sudden changes, the differential booster is used.

27. The effect of a battery in smoothing out the load line on a station is shown by Fig. 14. The heavy line indicates graphically the variation in the total current during a certain day. The lowest point, about 85 amperes, is reached between 3 and 4 o'clock in the morning; then it rises abruptly at 6 o'clock and continues to increase until 9, falling again towards noon, and attaining its maximum value at 6 in the evening, whence it falls rapidly and continuously. It is evident that to operate such a road, a plant would have to be provided with generators capable of furnishing 2,700 amperes to the line, and probably more on some occasions; but this amount is required during only a short

period, and some of the plant must remain idle or work inefficiently for a greater part of the 24 hours. The average current is about 1,276 amperes, and a line drawn through this point indicates the current output if the load were steady all day and the same in total amount. It would obviously, then, be an advantage if the high parts of the load could be brought down and the low parts brought up, and

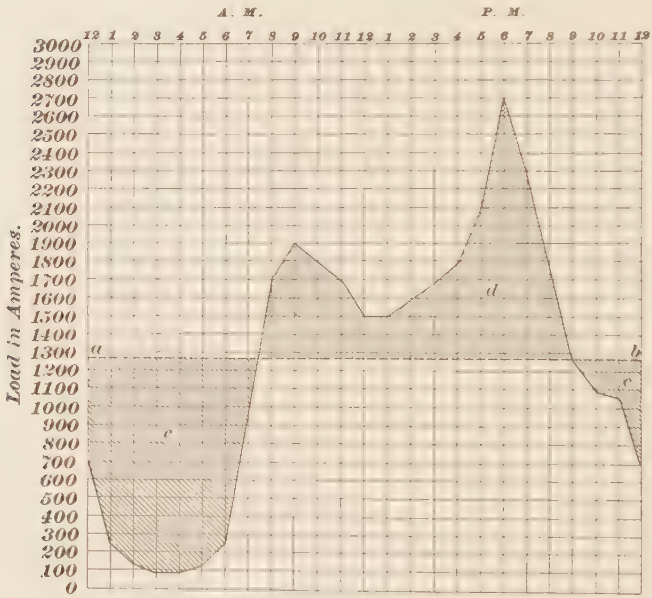


FIG. 14.

an equalization of the load thus effected. The storage battery can do this. If it were installed in such a station, the dynamos would be called on to deliver only about one-half of the current, 1,300 amperes instead of 2,700 amperes, and would therefore have to be but one-half the size; the engines and boilers could also be correspondingly smaller. In the diagram, the shaded portion marked *c* represents the charge given to the accumulators; *d* represents the discharge. Of course, in actual practice it would be almost impossible to bring the load on the generators down to a straight line

like *a b*, but nevertheless it may be made so uniform that the variations put but little strain on the machinery.

On small roads the fluctuations in load are especially severe. The upper curve, Fig. 15, shows the load curve taken from a small station. It is at once apparent that the load fluctuations are rapid and violent, as the curve represents a period of only 5 minutes. The lower curve shows how the load on the generators was smoothed out when the batteries were installed. The battery consists of 262 chloride cells. Each cell consists of 9 plates about 10½ inches square

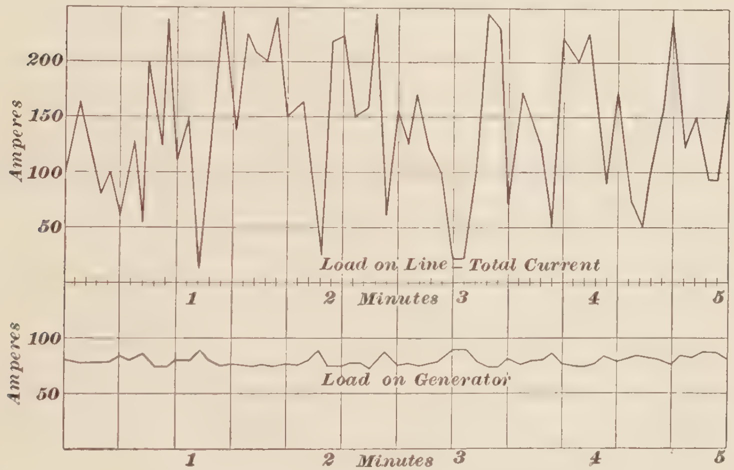


FIG. 15.

suspended in glass jars having outside dimensions of 10⅝ in. × 12½ in. × 15½ in. These jars are of sufficient size to permit of the addition of 4 more plates to the elements, thus insuring a 50-per-cent. addition to the capacity, should it be needed in the future. Each cell is on a wooden tray filled with sand and supported by glass insulators. On full charge, the battery has a capacity of 40 amperes for 7 hours; or it can discharge at the rate of 160 amperes for a short time. As a matter of fact, the battery is often called on to discharge at a rate far in excess of this, sometimes 250 amperes being called for momentarily.

As a result of the heavy grades and the small number of cars operated, the fluctuations in the load are very violent. The power house is about $\frac{1}{2}$ mile from the lower end of the road, in the center of the heaviest but not the longest grade. The machinery for generating the 500-volt direct current consists of one 60-kilowatt generator and one differential booster, both belted to the same engine. To clearly see the great advantage obtained by the use of the storage battery in this particular case, it will be best to study the load diagram given in Fig. 15, which was plotted from readings taken on the line and generator. These readings were taken every 5 seconds for a period of 5 minutes at the time of heavy load. It will be noted that the load on the line varied from about 15 amperes to about 250 amperes, but the load on the generators varied comparatively little.

Many other instances could be cited to show the position that the storage battery now holds in the electric-railway field. The batteries of today are made of liberal size for a given rated output and are mechanically strong, so that they are free from the old-time trouble of buckling. The plates are carefully prepared and live their natural time without dropping all their active matter in the bottom of the containing vessel. It is not to be imagined, however, that storage cells give no trouble and require no care, for, like all other electrical apparatus, they must be looked after if they are to give satisfactory service.

POWER ESTIMATES.

28. The problem of deciding what capacity the station dynamos must have in order to operate a given number of cars on a given road is a complex one, in that it involves conditions peculiar to each case and calls for the use of quantities that must to a great degree be guessed at or assumed. Among the factors that must be considered in solving the problem are: Weight of equipment; number of cars; speed of cars; topography of the road (grades, curves,

etc.); character of traffic; condition of line and rail return; manner of handling the equipment.

29. Weights of Cars.—The weight of an equipment, not including passengers, depends on the length and style of the car and on the weight of the motors. A modern open car just as it leaves the painter, with no equipment on it save the roof, wall, and light wiring, weighs about 320 pounds per foot, measured over all. A 20-foot body, then, would weigh in the neighborhood of 6,400 pounds; a 30-foot body, 9,600 pounds; a 35-foot body, 11,200 pounds, and so on. An open car equipped with motors of the proper size will weigh about 650 pounds per foot. This gives a 20-foot car a weight of 13,000 pounds; a 30-foot car, 19,500 pounds; a 35-foot car, 22,750 pounds. In designating the length of closed cars, it is customary to measure between the outsides of the bulkheads (end walls) and not between the bumpers. A modern closed car just as it comes from the painter, free of equipment, weighs about 395 pounds per foot of length between bulkheads. With the proper sized equipment, closed cars weigh about 880 pounds per linear foot. It will thus be seen that closed cars weigh more per foot than open cars. Up-to-date equipments complete weigh about 300 pounds per horsepower. This includes motors, trucks, hand-brake rigging, etc. The above figures may not exactly fit all cases, nor should they be expected to; but they have been averaged from observations made on standard equipments and will give a fair idea as to the value of these quantities. To the dead weight of the equipment must be added the weight of the passengers.

30. Current Required for Operating Cars.—We will assume that the cars to be operated weigh, with their probable average load, 10 tons; that they are to average 14 miles per hour; and that 6 cars are to be operated. The road is assumed to be level and free from curves. Now, it is an experimentally determined fact that *to urge 1 ton along at the rate of 1 mile per hour on a level rail requires an expenditure of about .06 horsepower applied to the wheels of the car.*

The experiment, of course, was not made on a car weighing only 1 ton. It was actually determined from the power required to drive a car weighing several tons 1 mile per hour and the power per ton derived by dividing by the number of tons.

Allowing an efficiency of 70 per cent. between the trolley wire and the rail would mean that, in order to get .06 horsepower applied mechanically to the car wheel, it would be necessary to apply to the motors electrically $\frac{100 \times .06}{70} = .086$ horsepower. Now, .086 horsepower $= .086 \times 746 = 64.156$ watts, which at 500 volts means a current $= \frac{64.156}{500} = .128$ ampere. Then, to push 1 ton of weight along a level rail at the rate of 1 mile per hour requires the absorption of .128 ampere at 500 volts. Now, the amount of current required to run a car is proportional to its weight, and within certain limits it is almost proportional to its speed. To push a 10-ton car along at the rate of 1 mile per hour would require a current of $10 \times .128$ ampere $= 1.28$ amperes, and to push the 10 tons along at the rate of 14 miles per hour, the assumed average speed, would require a current of 14×1.28 amperes $= 17.92$ amperes. As there are 6 cars and each car averages 17.92, say 18 amperes, to run the 6 cars would require a current of 6×18 amperes $= 108$ amperes, and this would represent the theoretical capacity of the dynamo required to run the road. Practically, this would be figuring too close, as there are times when one car alone will take as much current as this, if the controller is handled poorly, with the result that if the circuit-breaker were set so as to be any protection to the dynamo, it would be constantly flying out and delaying traffic. A dynamo of twice this current capacity would be more in order; then there would be some margin to allow for extra cars and increased headway.

The larger a system is, the nearer together may the theoretical and practical values of the station output be made, for then the fluctuations of a single car are not as large a

percentage of the total load. For example, one of the cars above averages 18 amperes, but if there were only one car on the road and the breaker were set to act at 18 amperes, it would be impossible to start that one car at all.

31. Current on Grades.—It is useful to know also that the current taken by a car is almost directly proportional to the steepness of the grade that it may be ascending. It is easily seen that it cannot be exactly proportional, because a 1-per-cent. grade is infinitely steeper than a 0-per-cent. grade, or level. The approximate relationship is this: *If it takes .128 ampere to push 1 ton along a level at the rate of 1 mile per hour, it will take approximately 10 × .128 ampere to push it up a 10-per-cent. grade at the same rate.* On the lower grades this relationship is not as true as it is on the higher ones.

32. Formulas for Power Estimates.—The figures just given will be found to give approximately close results. A number of formulas have been devised to calculate the power required by cars under certain conditions, but it is evident that any such formulas are at best only approximate, because several elements always modify the power taken. For example, the running gear may be in bad shape or the motors may be inefficient; the roadbed may be in bad condition or there may be excessive friction on some of the curves. Tests on different cars might therefore lead to results varying considerably from those given by the formulas that follow.

33. Force Required to Move Car on the Level.—The drawbar pull per ton weight required to move a trolley car on a level track at a uniform speed is somewhat higher than on steam roads. It will generally require a horizontal effort of about 25 pounds per ton to keep a car moving uniformly, and it will of course take a much greater effort than this to start the car, because the friction of rest is greater than the friction when the car has once started to move.

For obtaining the horizontal effort applied to the wheels, we may use the formula

$$f = 25\ w_t, \qquad \textbf{(1.)}$$

where f = force in pounds,

and w_t = weight of car in tons.

That is to say, *the force required to move a car over a level track in average condition is 25 pounds for every ton that the car weighs.*

EXAMPLE.—What force will be required to move a car, its weight being 9 tons ?

SOLUTION.—The weight of car $w_t = 9$ tons, and the force required will be, by formula **1**,

$$f = 25 \times 9 = 225 \text{ lb. Ans.}$$

34. When a grade has to be taken into account, the perpendicular distance in feet ascended in 1 minute multiplied by the weight of car will give the power in foot-pounds expended in raising the car; the horizontal distance in feet traveled in 1 minute multiplied by the force in pounds necessary to move the car will give the power in foot-pounds required for a level track. The sum of these values divided by 33,000 will be the total horsepower at the wheels. Loss of power in the transmitting mechanism will necessitate a larger figure for the power supplied to the motors, this depending on the efficiency of the apparatus. We may express these several operations in a single formula, as follows:

$$H = \frac{h\,w + D\,f}{33{,}000\ \mathsf{E}}, \qquad \textbf{(2.)}$$

where

H = total horsepower required for motors;
h = perpendicular distance in feet ascended in 1 minute;
w = weight of car in pounds;
D = horizontal distance in feet traveled in 1 minute;
f = force in pounds necessary to move the car;
E = motor efficiency expressed as a decimal part of 1.

The horsepower required to propel a car up a grade is equal to the product of the height in feet ascended and the weight of car in pounds plus the product of the horizontal distance in feet traveled per minute and the force in pounds necessary to move the car, this sum being divided by 33,000 times the motor efficiency expressed as a decimal part of 1.

EXAMPLE.—If a car with passengers weighs 8 tons and it is desired to take it up a 6-per-cent. grade at a speed of 10 miles per hour, what horsepower must be delivered to the motors, assuming that the efficiency between the trolley and wheels is 70 per cent.?

SOLUTION.—The car will cover in 1 minute $\frac{10 \times 5,280}{60} = 880$ feet $= D$, and on a 6-per-cent. grade this will correspond to a vertical distance of $880 \times .06 = 52.8$ feet $= h$. The weight of the car expressed in pounds $= 8 \times 2,000 = 16,000$ pounds $= w$. The force required for propulsion is, by formula **1**, $f = 25 \times 8 = 200$ pounds, and the efficiency being 70 per cent., $\mathsf{E} = .70$.

Then, by formula **2**, we have

$$H = \frac{h\,w + D f}{33,000\ \mathsf{E}} = \frac{844,800 + 176,000}{23,100} = 44 \text{ H. P. approximately. Ans.}$$

35. It will be of interest to work out this problem by using the data given in Arts. **30** and **31**. The efficiency has been taken as 70 per cent. in both cases; so we will take the current as $6 \times .128$ ampere per ton weight per mile per hour. The total current would then be $6 \times .128 \times 8 \times 10 = 61.44$ amperes. At 500 volts, this would be equivalent to $\frac{61.44 \times 500}{746} = 41.2$ horsepower. This comes out somewhat smaller, owing no doubt to the approximation introduced by taking the power as directly proportional to the grade. For approximate calculations, however, the agreement is sufficiently close.

36. The *power* required in going around curves depends on their radius and on the construction of the truck. The power required for starting may be taken as the same as that for rounding curves.

37. It has been found that a *force* of about 70 pounds per ton weight of car is required to start a car or to keep it in

motion when rounding curves. When starting on a grade, the effort must be greater in proportion to the percentage of rise, and for this condition add 20 pounds to the 70 pounds for every ton weight for each 1 per cent. of grade.

Expressed as a formula, the force required will be

$$f' = (70 + 20\,x)\,w_t, \qquad (3.)$$

where f' = force in pounds;
x = per cent. grade;
w_t = weight of car in tons.

The force in pounds required to start a car on a grade is equal to the weight of the car in tons multiplied by 70 plus 20 times the per cent. grade.

On a 2-per-cent. grade the force required in starting will therefore be $f' = [70 + (20 \times 2)] \times 1 = 110$ pounds per ton.

EXAMPLE.—What force will be required to start an 8-ton car on a 5-per-cent. grade?

SOLUTION.—According to formula **3**, the force will be

$$f' = (70 + 20\,x)\,w_t = [70 + (20 \times 5)] \times 8 = 1{,}360 \text{ lb. Ans.}$$

38. The limit of adhesion may be $\frac{1}{8}$ of the weight; therefore, on a level track the maximum force that could be applied without slipping would be $\frac{2000}{8} = 250$ pounds per ton. If the rails were muddy or greasy, much less than this force would be used, while very clean, dry rails might increase this amount. In ordinary street-railway service the rails are usually rather slippery, and often, in consequence, the adhesive force may be low. We may calculate the grade on which slipping will occur when starting the car and also when it is already in motion in the following manner:

Let a = ratio of adhesive force to weight on drivers;
w' = weight on drivers in pounds;
w_t = weight of car in tons of 2,000 pounds;
G_s = per cent. grade at which slipping occurs.

Then, slipping will occur at starting on a grade

$$G_s = \frac{a\,w' - 70\,w_t}{20\,w_t}.$$

But $w' = 2{,}000\, w_t$, when the whole weight of the car is on the drivers, in which case the limiting grade for starting

$$G_s = \frac{2{,}000\, a\, w_t - 70\, w_t}{20\, w_t} = \frac{2{,}000\, a - 70}{20} \text{ per cent.} \qquad (4.)$$

The limiting grade for starting a car, when the whole weight of the car is on the drivers, is equal to 2,000 times the ratio of adhesive force to weight on drivers minus 70, this difference being divided by 20.

When $\frac{1}{y}$ of the weight is on the drivers,

$$G_s = \frac{\frac{2{,}000\, a}{y} - 70}{20} \text{ per cent.} \qquad (5.)$$

The limiting grade for starting a car, when a fraction of its weight is on the drivers, is equal to that fractional part of 2,000 times the ratio of adhesive force to weight on drivers minus 70, this difference being divided by 20.

Example.—If a car weighs 7 tons and all its weight is on the drivers, adhesion being $\frac{1}{8}$ of this weight, will it start on a 7-per-cent. grade?

Solution.—The per-cent. grade at which slipping occurs at starting is, by formula **4**,

$$G_s = \frac{(2{,}000 \times \frac{1}{8}) - 70}{20} = \frac{180}{20} = 9 \text{ per cent.}$$

The car will therefore start on a 7-per-cent. grade, as 9 per cent. is the limit. Ans.

39. When the car is running, only 25 pounds per ton is necessary for propulsion, and the limit of grade which may be ascended is, when G_r = maximum grade which a running car will ascend,

$$G_r = \frac{\frac{2{,}000\, a}{y} - 25}{20} \text{ per cent.} \qquad (6.)$$

The limiting grade that a car will ascend, when a fraction of its weight is on the drivers, is equal to that fractional part of 2,000 times the ratio of adhesive force to weight on drivers minus 25, this difference being divided by 20.

EXAMPLE.—The limit of adhesion being $\frac{1}{6}$ the weight on the drivers, how steep a grade could be surmounted by a car with $\frac{1}{4}$ its weight on the drivers, starting from the level?

SOLUTION.—According to formula **6**,

$$G_r = \frac{\frac{2,000\,a}{y} - 25}{20} = \frac{\left(\frac{2,000}{4} \times \frac{1}{6}\right) - 25}{20} = 2.91 \text{ per cent. Ans.}$$

40. The foregoing data and formulas will enable approximate calculations to be made regarding the power required for a given number of cars. It is unsafe to give values of the power to be allowed per car, because there is such a wide variation in the size and weight of cars that such figures are not generally applicable. The safest method is to calculate the power required for any given case by taking into account the weight of the cars, speed, steepness of grades, etc., as indicated in the above formulas.

THE LINE.

41. The term **line**, when used in connection with a street railway, covers quite a large field of work; in the first place, the line may be an overhead-trolley system, a conduit system, a third-rail system, or a high-potential transmission line. Also, the name can include any of the several sectional surface systems, none of which, however, are in general enough use to warrant its consideration here. Whatever the system may be, its consideration calls for a study of the active trolley wire, its feeders, and their means of support.

OVERHEAD LINE CONSTRUCTION.

42. General Features.—When **overhead construction** is spoken of, it is generally understood to refer to the common overhead-trolley system that is used wherever it is permitted, because it is so much cheaper than any of the other

systems. Overhead construction includes the setting of the poles, the stringing of the feed wires and the trolley wire, with its span wires, guard wires, anchor wires, insulating hangers, coupling devices, switches, etc. The feed wires, or feeders, i. e., the wires communicating directly between the generators at the station and the several points of distribution, are carried overhead or are laid underground if necessary. When the feeders are carried overhead, it is the rule to support them on cross-arms from the same poles that support the span wires and trolley. Sometimes, however, if the feeder followed the line of the track, it would be unnecessarily long. In such a case, its route would lay across country or across town, as the case might be.

43. In Fig. 16, *P* is the site of the power house; *k–a–C B–b–e* is the trolley wire, which of course has to follow the track. The trolley wire is divided into two sections, *a* and *b*, separated by the circuit-breaker *C B*; the term circuit-breaker used in connection with line work denotes a fitting for putting a break, or insulating joint, in the trolley line. Each section of the wire is fed by its own feeder. Feeder b_1 feeds into section *a* at *a* and follows the line of the track up to that point. Feeder b_2 feeds into section *b* at *b*, but instead of following the track and taking the long path around, as shown by the dotted line, it cuts across, as shown by the full line, thus effecting a great saving in length. It is, as a rule, cheaper in such cases to take the short cut, even if a pole line has to be erected just for the feeder, because great length in a feeder not only means a

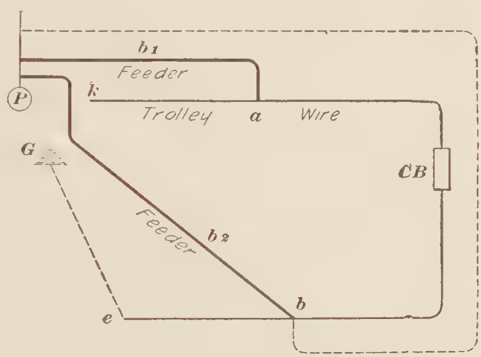


FIG. 16.

great outlay in copper, but it also means that the additional resistance helps to defeat the purpose of the feeder—that of keeping the voltage up to a practicable value on the line.

44. Most overhead-trolley systems use a **rail return**; that is, the current leaves the power house by way of the feeders and perhaps the trolley wire, passes through the car motors and returns to the power house by way of the rails, the earth, and whatever water, gas, or other pipes may happen to parallel the track. The return circuit, then, is an item of just as much importance, as far as conductivity is concerned, as is the overhead work, and in some cases it is of more importance, because when the rail return is bad, so much current follows the path of neighboring pipes as to injure them and bring on lawsuits.

A glance at Fig. 16 will show that although feeder b_2 allows the current a short path from the power house to the point of distribution b, it does not provide a short path back to the power house. To reach the power house, the return current must follow the rail, and it would be very easy under such conditions for a greater drop to take place in the track return than in the overhead feeder. It is easily seen that, if a ground wire were run from some point on the rail in the neighborhood of b, or even from the end e to the ground bus-bar at the power station, it would greatly improve the conditions of the service.

Should it be found desirable or should circumstances make it necessary to put the feeders underground, they should be handled with great care and should be substantially protected from any liability to abrasion, since faults are somewhat difficult to locate and expensive to remedy. The feeders, as a rule, are encased in a lead sheathing, which not only is a protection against abrasion and moisture, but leaves the feeder pliable and easy to handle. A break in the sheathing due to a bruise or a kink may not cause any trouble for months after the feeder has been in active service, but in course of time moisture will work through and establish conditions for setting up a leakage current, which

will gradually convert the fault into a short circuit. Even in stringing feeders overhead on iron poles, a little carelessness on the part of the linemen will give rise to the same trouble. The ordinary practice in stringing such feeders is to set the reel upon which the feeder wire is wound near the first pole and on the off side; one end of the wire is then passed over the cross-arm of the pole and a horse or car is hitched to it to pull it to the next pole, over the cross-arm of which it is also raised and the operations continued until the wire is in place. If there happens to be a snag on the cross-arm or if the feeder gets caught, a hole is cut in its insulation. If, after the feeder is secured in place on its insulators, the injured part falls between poles, it can do no harm, unless a telephone or light wire happens to fall across it at some time; but if, as often happens, the abraded part falls over the cross-arm, then the first time a heavy wind lifts the feeder off the insulator and lets it down on the iron cross-arm, trouble begins.

FEEDERS.

45. The whole distributing system of an electric railway may be generally divided into two parts—the **feeders** and the **working conductor.** The latter usually takes the form of a trolley wire in overhead work, but it may be a third rail or the conductor rail in a conduit system. The feeders are usually in the form of heavy cables run out from the station to supply different sections of the working conductor. Feeders may be run overhead or underground. In small towns and cities or on cross-country roads, they are run on poles, because this is the cheapest construction. In large cities, however, they are run underground. City ordinances often prohibit running them overhead on account of their unsightliness and also on account of their being a nuisance and source of danger in case of fires. Underground construction is expensive, but it has its advantages. Electric-railway companies objected very strongly when

they were first required to put their feeders underground, but many of them are now strongly in favor of it. Underground wires are not disabled by snow and sleet storms, and on the whole their service is more reliable than that of overhead wires.

Where feeders are run underground, they are usually in the form of lead-covered cables. These are pulled into ducts, and manholes are provided at intervals to allow access to the cables for making repairs and locating faults.

46. General Methods of Feeding. — The simplest method of line construction is to use a single wire, serving both the purpose of trolley wire and feeder; but with a heavy load, the drop of potential at the end of the line, except in special cases, would be too great if the trolley wire alone were used. It is more satisfactory to run a heavy cable alongside of the trolley wire and tap it into the wire

FIG. 17.

at intervals along the route: the two together will carry the load with much less loss in voltage than will the trolley wire alone. Such a plan is shown in Fig. 17, where m n is the trolley wire, a b the feeder, and f, f the several taps. The power station is supposed to be at one end of the line at S. It would be a much more economical arrangement were the power station in the center, as shown in Fig. 18, so that it might feed in both directions and thereby halve the distance from the power house to either end of the line.

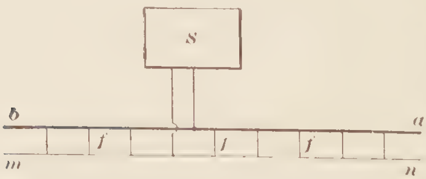


FIG. 18.

If the trolley wire is divided into a number of sections c, d, e, f, g, each connected at its center to the

feeder $a\,b$, as shown in Fig. 19, the drop in potential at any point would be due only to the feeder and that portion of the trolley line between the point in question and the tap line. In case

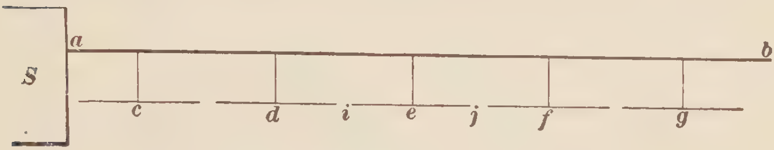


FIG. 19.

of a fire at any place along the route or in case of a ground on a bridge or in a tunnel, the power could be shut off in that district without disturbing the other parts of the line, so that the whole road would not be shut down. In order to do this, each tap wire should be provided with a switch that is mounted on the pole at the point of connection to the feeder. Fig. 20 shows a line switch for this purpose. It is mounted on the pole and the lower terminal is connected to the trolley. When the switch is opened, the blade can be thrown all the way down and the door closed. All the exposed parts are then dead and the switch cannot be closed until the door is unlocked. The several sections of the trolley wire are well insulated from one another by line circuit-breakers, or section insulators, which will be described later.

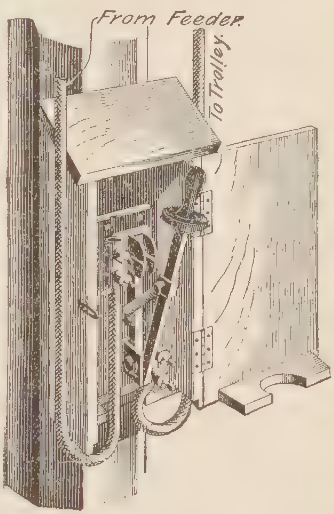


FIG. 20.

47. Fig. 21 is a plan of feeder wiring that approaches more nearly the trend of present practice than any of the other plans so far shown. It approaches the condition

where the trolley wire is divided up into several sections, each of which is provided with its own feeder. But in the case shown in Fig. 21, each feeder supplies several sections of trolley wire by means of extension feeders or

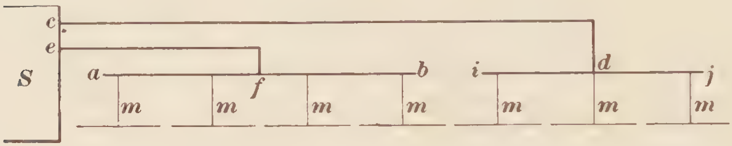


FIG. 21.

mains *a f*, *f b* on the end of the main feeder and an independent tap running to each section of trolley.

Fig. 22 shows the best plan for a feeder service. In this case, each trolley section has a feeder of its own. Of course, the feeder is tapped into its section in as many places as may be deemed advisable. Each feeder and its section of

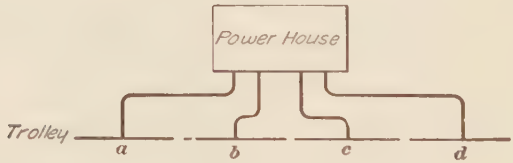


FIG. 22.

trolley wire may be looked on as a single unit, and the idea can be extended to any system, however large. Such a plan not only simplifies calculations, but limits the field for troubles as well. Any trolley section may be cut out by means of its feeder switch.

48. Overhead feeders are usually in the form of heavy stranded cables covered with weather-proof braided insulation. If a very large feeder is not required, solid wire may be used or two or more wires may be run in multiple to make up the requisite cross-section. The accompanying table

gives the make-up of triple-braided weather-proof railway feeder cables as made by the American Electrical Works.

Size.	Style of Conductor.	Approximate Weight per Mile. Pounds.
1,000,000 C. M.	61 wires, .128 each.	19,000
950,000 C. M.	61 wires, .125 each.	18,250
900,000 C. M.	61 wires, .122 each.	17,280
850,000 C. M.	61 wires, .118 each.	16,320
800,000 C. M.	61 wires, .115 each.	15,360
750,000 C. M.	61 wires, .111 each.	14,400
700,000 C. M.	61 wires, .107 each.	13,450
650,000 C. M.	61 wires, .103 each.	12,480
600,000 C. M.	61 wires, .099 each.	11,600
550,000 C. M.	61 wires, .091 each.	10,560
500,000 C. M.	49 wires, .101 each.	9,800
450,000 C. M.	49 wires, .096 each.	8,600
400,000 C. M.	49 wires, .090 each.	7,500
350,000 C. M.	49 wires, .085 each.	6,500
300,000 C. M.	49 wires, .078 each.	5,500
250,000 C. M.	49 wires, .071 each.	4,860

TROLLEY WIRE.

49. In the early days of electric railways, the trolley wire was much smaller than that now used. No. 2, 3, or 4 B. & S. soft copper wire was used in many cases, but it was soon found that this wire was not strong enough mechanically. Hard-drawn copper wire is now used in most cases, and the size is generally from No. 0 to No. 000; in some cases, No. 0000 wire is used. Wire smaller than No. 0 should not be used. Hard-drawn copper wire has a little higher resistance than soft-annealed wire, but its tensile strength is very much greater; hence its use for trolley wire. Where a very strong wire is required, phosphor-bronze is sometimes used.

50. Shape of Trolley Wire.—Trolley wire is nearly always round in cross-section. This answers for ordinary work in towns and cities where the speed is not high. Fig. 23 (*a*) shows the ordinary round wire held by a soldered ear. The ear is tapered down to an edge, so that it will allow the under-running trolley wheel to pass as smoothly as possible. Even if the fins on the ear are thin, there is always more or less of a jump when the wheel passes under the hanger, and this gives rise to trouble if the car runs at high speed. The sparking caused by the jump also eats the hanger away and causes breakage in course of time. The jump is even more pronounced if ears which clamp the wire, instead of being soldered, are used. Clamping ears project more than soldered ones, and hence there is more of a knock when the wheel passes under them.

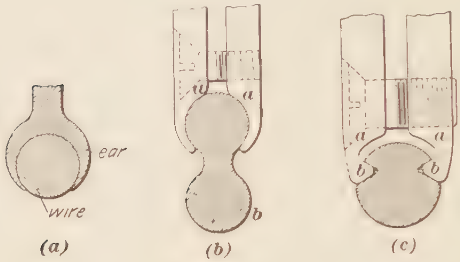


FIG. 23.

For cross-country or interurban roads, where high speed is attained, it is very desirable to have the trolley wire so suspended that it will offer a smooth running surface for the trolley. Fig. 23 (*b*) shows a wire designed to accomplish this. It is the shape of a figure 8 in cross-section and the upper part is gripped by the clamp ears *a*, *a*, the lower part *b* being free from obstruction. The objection to this style of wire is that if it becomes twisted between supports, so that it lies crosswise, the wheel does not run well.

Fig. 23 (*c*) shows another style of wire introduced by the General Electric Company. This wire is also supported by clamp ears *a*, *a*, and the surface presented to the trolley wheel is smooth. The wire is practically circular in cross-section, with the exception of the two grooves *b*, *b* in the side, so that if the wire twists between supports it does not interfere perceptibly with the smooth running of the wheel

when high speeds are attained. Fig. 24 shows clearly the method of supporting this wire.

When soldered ears are used, the obstruction offered is so slight that a round wire answers in the great majority of

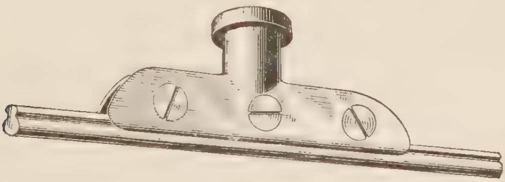


FIG. 24.

cases. When clamped ears, however, are desired, and when high speeds are developed, these special shaped trolley wires will be found advantageous.

METHODS OF ARRANGING TROLLEY WIRE.

51. There are three styles of support for trolley wires: they may be suspended directly from brackets on poles at the side of the road; or a double track may be provided with center poles carrying the wires on a projecting arm on either side; or the poles may be placed at the sides of the street and the trolley wire supported by span wires stretched across.

52. Span-Wire Construction.—This is the most common method of suspension, and it is preferred for the following reasons: In the first place, it does not obstruct the center of the roadway as the center-pole construction does; in the second place, there are places where only one side of the road can be used, as on country roads, where passages for two teams must be left outside of the track. Again, where a single track is laid with the prospect in view of making it a double track if the traffic warrants doing so, the side-pole, span-wire construction leaves very little additional work to be done when the time comes for doubling the track. In such a case, it is often the practice to string two trolley wires

alongside of each other about 8 inches apart. As long as the road is a single-track road, the cars use one wire going one way and the other wire coming back; this saves overhead special work at turnouts and saves copper in the feed wires. When the time comes for doubling the track, it is only necessary to slide one wire over into place and see to its insulation from the ground. In such straightaway construction, it may be that no feeders are used, in which case the road cannot be divided into sections, but the two wires must be continuous from the power house to the end of the line.

In Fig. 25, *a b* is one trolley wire and *c d* is the other; *T* is a turnout—a switch where cars can pass each other, and the other dotted line *e f* shows the position of the wire *a b* after it has been moved over to the second track. It is easy to see that the parallel construction does away with the necessity of any overhead special work at the turnouts. If all the turnouts are placed on the same side of the track, it leaves one wire straight.

FIG. 25.

One rather unusual condition, under which the side-pole, span-wire method has a decided advantage, is where a projected road has trouble in obtaining right of way through the country. One owner may give the right of way in front of his property, but the owner across the road may refuse it, so that the track will have to be laid on one side of the neutral line. It may be necessary to do this several times in the course of a few miles, with the result that the line zigzags from one side of the road to the other. If the center-pole construction is used, the poles will have to zigzag with the track; but if side poles are employed, it will be necessary to make only the trolley wire itself conform to the serpentine track construction by sliding the wire one way or the other on the span wire. In course of time, if the track can be straightened, the only change necessary in the overhead construction is to move over the trolley wire.

53. Fig. 26 shows the general arrangement of a span-wire suspension. In this case iron poles are shown, so that an insulating turnbuckle is used between the pole and the span wire. The trolley hanger is also insulated, so that there is high insulation between the trolley wire and the

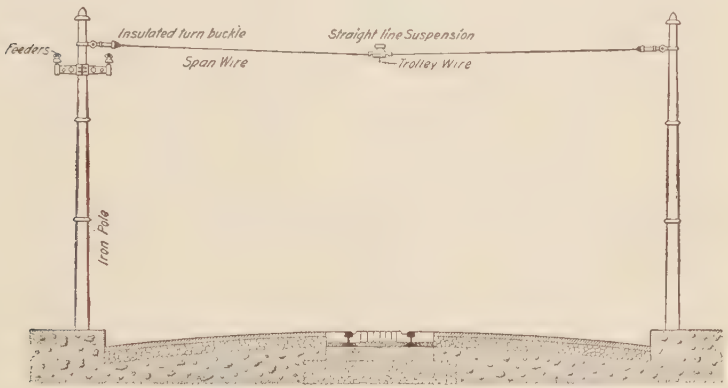


FIG. 26.

ground even though iron poles are used. The feeders are carried on cross-arms bolted to the poles. Where wooden poles are used, the insulated turnbuckles are often omitted. An eyebolt is simply passed through the pole and the span wire is stretched by screwing up a nut.

54. Center-Pole Construction.—Center-pole construction can be used to good advantage on very wide streets, where the poles will not be in the way. If ornamental center poles are used, the general appearance may be made very pleasing. Sometimes arc lamps are mounted on every other pole, thus adding to the general effect at night. Where ornamental construction is used, the unsightly feeders are generally run underground, but if this is impracticable or if it is undesirable to run the avenue feeders in a conduit, the same effect can be obtained by running the feeders overhead, but up a street that parallels the main avenue. In this case, the taps must run from the feeder in the side street to the trolley wire. This feed tap disappears

into the ground just off the avenue and does not show again except where it is spliced to the trolley wire. From the side street to the pole it is carried in a tube; it then passes up through the center of the pole to the bracket and out to the wire.

55. Side-Bracket Construction.—When this construction is used, the track is generally on one side of the street. It is used most extensively for cross-country lines where

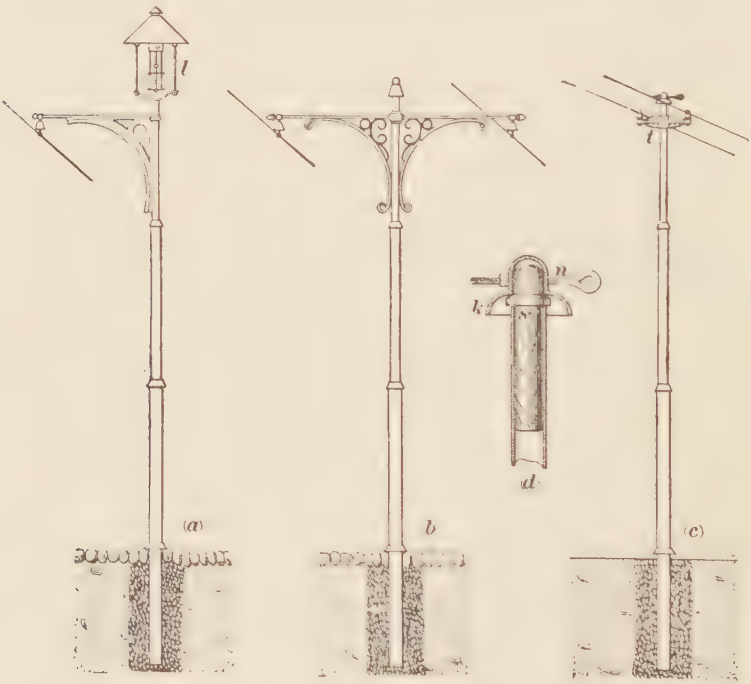


FIG. 27.

a single track runs along one side of the road. For this class of work, cheap gas-pipe brackets are generally used, and since the construction calls for only one pole, whereas a span wire requires two, it is inexpensive.

56. Steel and Wood Poles.—At the present time, the poles used are either steel or wood. For cross-country or

suburban roads, wooden poles are as a rule selected, because appearances are not so much a matter of consequence, and they are even used in city streets where no very strong objection is made to them. Steel poles are, however, much the better for city streets. There are a great many tubular steel poles of the telescope type in use in cities; in fact, many cities will not allow the use of wooden poles on the ground that they are unsightly. Seamless steel-tube poles are also coming much into favor, as they are strong and last a long time. Such poles are invariably set in concrete.

57. Tubular Steel Poles.—Fig. 27 shows a tubular pole adapted to the various types of construction; (*a*) is the side bracket, (*b*) the center pole, and (*c*) the plain pole for span-wire construction. The poles are about 30 feet long, the lower section being 6 or 8 inches in diameter and the others 1 inch smaller successively, fitting inside of each other with telescope joints that ought to be at least 18 inches long. Fig. 27 (*d*) is an enlarged view of the top of the pole shown in (*c*) without a bracket. It shows the insulated top *k* supported on a wooden block *s* and carrying the tension bolt *n*, to which the span wire is secured through the medium of an insulator. The cross-arm *t* carries feeders to supply current at distant points. The pole may also be utilized to carry an arc lamp shown at *l* in (*a*). Instead of a tension bolt, there may be placed on the top of the pole, as shown at *a*, Fig. 28, a ratchet provided with a counter-balanced pawl *b*, engaging with the teeth. The base *c* has flaring sides to shed rain and fits into the insulating wooden block *d*. In a slightly modified form, the ratchet may be fastened to the side of the pole

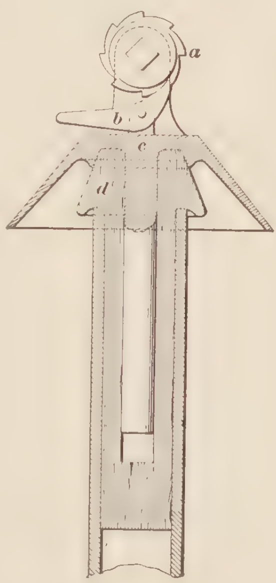


FIG. 28.

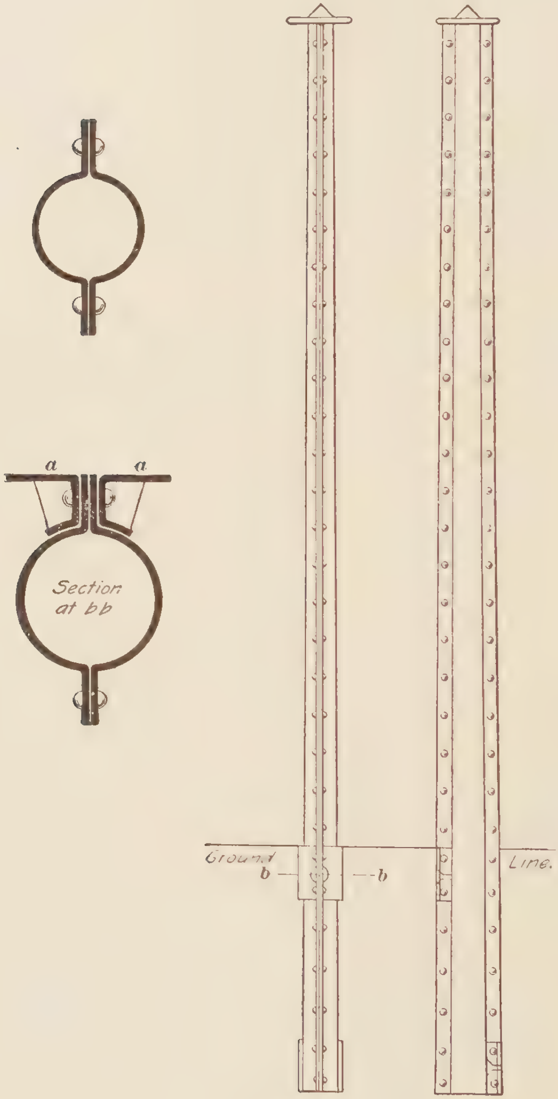


Fig. 29.

at any point or bolted to a wooden pole. In addition to these arrangements, a clamp may be used on the pole in connection with a turnbuckle, as shown in Fig. 26.

58. Structural-Steel Poles.—Steel poles are sometimes made in other than telescope tubular form. Fig. 29 shows a pole made of pressed steel halves riveted together. Pieces *a*, *a* are riveted on at the bottom and at the ground level, so that the pole will have a flat surface of considerable area to enable it to better withstand the strain due to the span wire.

Latticework poles are also largely used; they are neat and strong and can be painted inside and out. They are also easy to climb.

59. In both bracket and center-pole construction, it is now the practice to use a flexible support for the trolley-wire hanger, to prevent the destructive blow of the passing trolley wheel and reduce the sparking. Such an arrangement is shown in Fig. 30, which represents a form used for the side-bracket construction. A span wire *w* holding the hanger *h* is stretched tightly between two insulators *i*, *i'*; the outer one is secured to a bracket *b* and the inner one is held by a clamp on the framework. In the center-pole method of construction, the brackets extend on both sides, and when the pole is of wood, a hole may be bored through it to receive the span wire. Of course, in the ordinary side-pole, span-wire method of construction, no such device is needed to cushion the blow of a passing trolley, as this trouble is looked after by the natural flexibility of the suspension.

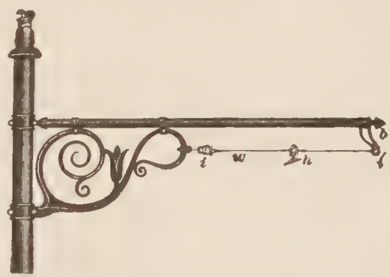


FIG. 30.

60. Wooden Poles.—For ordinary use, the diameter of the base of a wooden pole should not be less than 10 inches,

tapering to 6 or 7 inches at the top, which should be cut to a conical shape so as to shed water. The pole from the ground up may be round or octagonal. Octagonal poles look better, but poles naturally round last longer. It will be found to prolong the life of a wooden pole and also lessen the liability to current leakage if the part above the ground is covered with two coats of paint. The part that is to be under the ground should receive a preservative of some sort, such as tar.

61. Setting Iron Poles.—The lower end of the pole is sunk in the ground 6 or 7 feet and filled around with cement and broken stone. The amount of concrete to be used at the base of each pole cannot be laid down as a general rule, because it varies according to the soil encountered. In some places it is necessary to blast the holes for the poles in the solid rock ; in such a case only enough concrete need be used to give the pole a firm set. In other localities there may be no rock and yet the subsoil may have plenty of body, in which case the hole may be made about the diameter of an oil barrel and the space surrounding the pole filled in with concrete. The concrete is used to increase the surface on which the lateral pressure at the base of the pole acts. It must be borne in mind that the span wires are strung under considerable tension and that they tend to pull together the tops of the tube poles to which they are connected, and the poles will yield unless they are firmly fixed in the ground. The concrete sticks to the pole base as if it were a part of it, and in this way increases the diameter of the base and enables the pole to resist any effort to pull it over. Some soils are so very giving in nature that it is necessary to dig a hole several feet in diameter around the pole ; the pole is then set in concrete and the rest of the hole is tamped full of stones, broken brick, etc.

62. Guy Wires and Slanting of Poles.—Sometimes even the above treatment does not secure a setting that

can be relied on, so it is supplemented by a guy wire that puts a strain on the pole opposite to that exerted by the span wire. These guy wires are most often called for on corner poles that support feed wires turning at that point. To offset the tendency of the span wires to pull the tops of the poles together, the poles are all canted outwards, about 6 inches out of plumb. In some cases even more slant than this is needed. Too much stress cannot be laid on the importance of setting the poles properly and doing the work so that they will stay so ; for when a pole gives to the tension of the span wire, it makes a zigzag in the trolley wire, which is rigidly attached to the span wire through the medium of its insulator. As soon as the wire gets out of line the never-ending trouble of the car trolley pole jumping the wire begins. When the pole flies off at one span wire, it generally manages to strike the next one or two, and the trouble goes from bad to worse.

63. Setting Wooden Poles.—Wooden poles are not, as a rule, set with concrete, although there is no good reason why they should not be. When the side-pole, span-wire construction is used, the wooden poles should have their earth bearing increased by the proper disposal of several large stones. A couple of stones should be jammed into the hole alongside of the pole on the side away from the track and a couple more near the mouth of the hole on the side next the track. This will do a geat deal towards preventing the span wire from pulling the tops of the poles together. A piece of timber may be substituted for the stones on the track side, and in such a case should be about 3 feet long and 8 inches in cross-section. The outward slant of a wooden pole should be about twice that of a steel pole in the same soil, and when in position, the pole should be solidly tamped around to make a firm bed. The tamping should be done while the pole is free; if done while there is tension on the span wire, the effect will be just the opposite to that desired.

The selection of wooden poles for an extensive system should be left to a man thoroughly familiar with the work. The buying of metal poles is not such a risky undertaking, because they can be bought under guarantee to fill certain specifications, but almost any one not long identified with the business is liable to make mistakes in selecting wooden poles.

ELECTRIC RAILWAYS.

(PART 3.)

LINE FITTINGS AND LINE ERECTION.

THE TROLLEY WIRE.

1. The general arrangement of wiring for a double track is shown in Fig. 1. The poles *p* are placed not more than 125 feet apart measured along the road, and between opposite poles are stretched the **span wires** *s*. At intervals of about 500 feet and at the approach to all curves, **anchor wires** *a* are put up, being secured by special hangers, as at *h*. Anchor wires take up the strain on the trolley wire in the

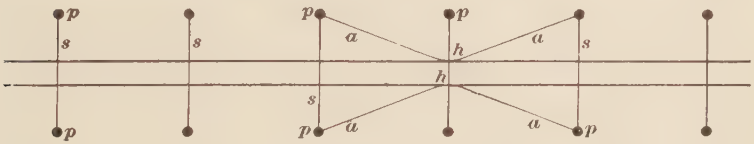


Fig. 1.

direction of its length, for it must be borne in mind that the trolley wire is put up under considerable tension, so that should it break it would draw apart in both directions if there were no anchor wires to hold it in position. The two general methods of stringing the trolley wire depend on whether it is put up dead or alive, i. e., whether the current is off or on. In the first case, the wire is run off the reel

For notice of copyright, see page immediately following the title page.

under the span wires and is then raised and tied temporarily to them; the tension is put on afterwards and the wire fastened to the insulators.

If the wire is put up alive, the reel is put on a flat car that is moved by a trolley car. As fast as the wire is paid off, it is fastened to the insulators, once for all, by a line crew that follows close behind. It may be necessary to go over the road afterwards and make a final adjustment, especially at curves and crossings.

2. Erection at Curves.—The method of securing the trolley wire at curves is shown in Fig. 2, where *A* represents

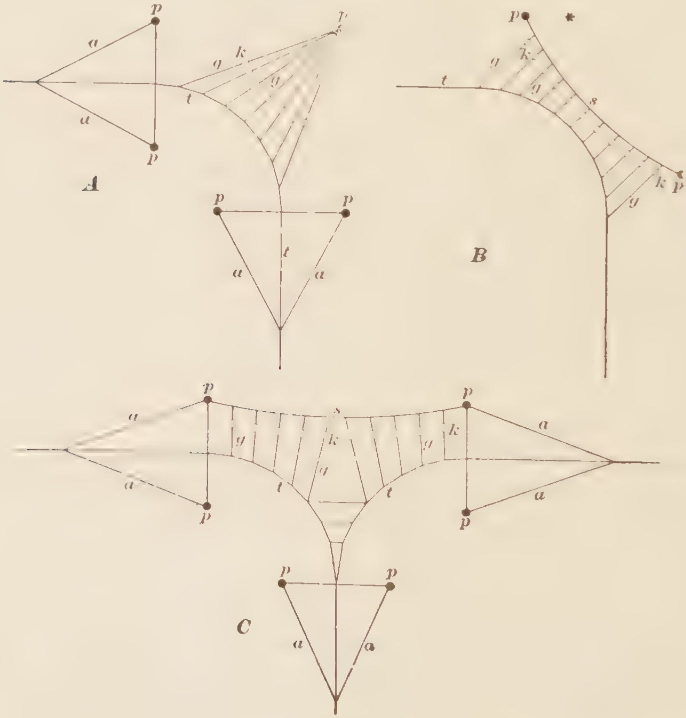


FIG. 2.

the arrangement of guy wires *g* attached to the trolley wire *t* when a single pole is used. Strain insulators are usually

inserted as shown at k, and the trolley wire, at the beginning of the tangent or straight portion, is held by anchor wires a. A flexible method of suspension is shown in diagram B, where a heavy span wire s holds up the guy wires; this form of construction tends to equalize the strains on the span wires, and is generally adopted in place of A, which is the older method. A double curve is shown at C, the different wires and poles being designated by the same letters as in the preceding layouts.

3. Offset in Trolley Wire.—In going around a curve, the trolley wire does not follow the center line between the rails as it would do if the trolley wheel were applied to the wire at a point immediately over the center of the car, but it is strung over towards the inside rail by a distance that depends on the radius of the curve. This departure from the center line of the track is shown in Fig. 3, where the curve r is the center line of the rails and t the path of the trolley wire. The amount of offset measured at the middle of a 90° curve at the point indicated by the arrows in the figure should be about as follows:

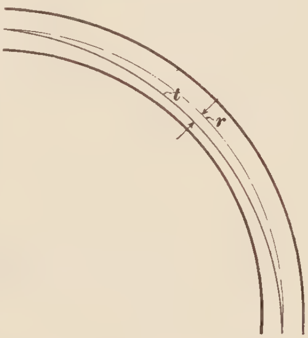


FIG. 3.

Radius of Curve in Feet.	Offset.
40	16 inches.
50	13 inches.
60	12 inches.
80	8 inches.
100	6 inches.
120	5 inches.
150	4 inches.
200	3 inches.

The object of the offset is to allow the trolley wheel to lie more closely to the wire; it would not do this so well if the

wire followed the center line of the track, as the wheel would lie diagonally across the wire and cause a large amount of wear on curves. Evidence of this can be seen on many old lines.

4. In some places **guard wires** are required above the trolley wires. These are strung about as shown in Fig. 4, being about 18 inches above and to one side of the trolley wire. The object in using guard wires is to prevent telephone or other wires from falling across the trolley wire. Guard wires are not used as much as they once were; they are usually of No. 6 or 8 B. W. G. galvanized-iron wire.

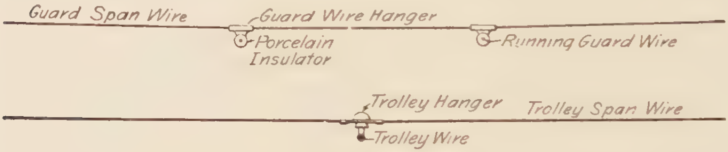


FIG. 4.

Span wires used to support the trolley-wire suspensions should be about No. 1 B. & S. steel wire, if No. 0 trolley wire is used, and should be well galvanized. The trolley wire should hang about 19 feet above the rail. Of course, there are places where this rule cannot be adhered to, for at steam crossings the wire must be higher than 19 feet and under elevated structures it must be much lower. The insulation must be as good as possible, not only to avoid current leakage itself, but also its direct effect, i. e., live poles.

5. Insulators are used in two places—at or near the pole and again at the trolley-wire hanger. Those in the span wire are called **strain insulators,** because they have to stand the tension or strain on the span wire. Fig. 5 shows a simple strain insulator. The span wires are attached to the two pieces *a*, *a* and the pull is taken up against piece *b*, which is separated from pieces *a*, *a* by insulating material. The whole insulator, with the exception of the two eyes, is covered with molded insulating material.

Fig. 6 shows a strain insulator and turnbuckle combined, the turnbuckle serving to stretch the span wire. In Fig. 6, *i* is a globe of hard molded insulating material. Into this ball, but not touching each other, are secured the eyebolt *e* and the straight bolt *s*; the turnbuckle *p*, which engages the

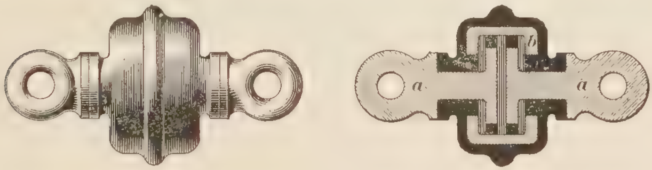


FIG. 5.

bolts *s* and *s'*, is fitted with right- and left-hand threads for regulating the tension, and the ends of the span wire are fastened to the device at *e* and *e'*. The turnbuckle is used not only for regulating the tension of the span wire, but also for correcting minor irregularities in the centering of the

FIG. 6.

trolley wire by paying out on one turnbuckle and taking up the other. When a ratchet is used, no turnbuckle is needed and the insulator takes the simple form of an insulating ball or cylinder with an eyebolt in each end, as shown in Fig. 5.

6. Trolley-Wire Suspensions.—The hangers for suspending the trolley wire are made in a great variety of designs, but in general they consist of three parts, namely, a casting of some kind that is held by the span wire or bracket, an ear that grips or is soldered to the trolley wire, and insulating material that separates the ear from the casting. Fig. 7 shows a common form of suspension with the ear removed; *a* is the main casting, provided with the grooved extensions *d*. The span wire passes through *d* and

around a, thus holding the hanger in place. The bolt c is bedded in molded insulating material and the casting

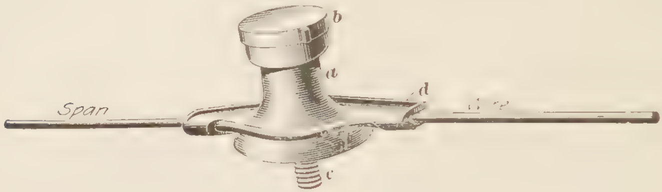


FIG. 7.

is covered by a metal cap b. The ear to which the trolley wire is fastened screws on c.

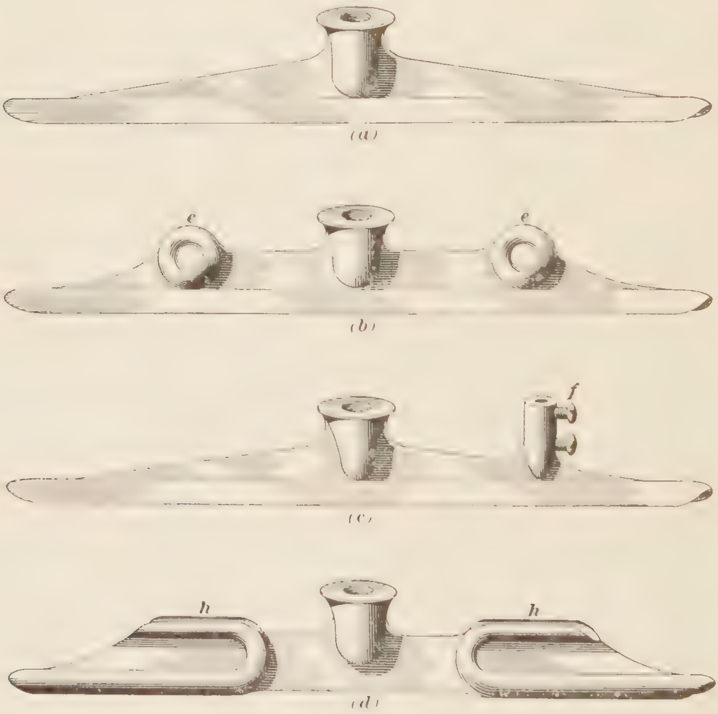


FIG. 8.

The metal castings for overhead fittings are made either of malleable iron or brass. The ears when soldered are

made of brass; those designed to clamp on the wire are usually made of malleable iron.

Fig. 8 shows four styles of ears intended for soldering to the trolley wire. These ears are provided with a groove on the under side, in which the wire lies. The ear shown at (*a*) is known as a **plain ear**; it is used for ordinary straight-ahead work. (*b*) shows a **strain ear,** so called because it is provided with lugs *e*, *e*, to which the wires *a*, *a*, Fig. 1, are attached. (*c*) is a **feeder ear**; it is provided with a lug *f*, to which the tap from the feeder attaches. (*d*) is a **splicing ear,** used where the trolley wire comes to an end at a hanger. This ear serves the double purpose of holding the wire and acting as a splice. There are two openings *h*, *h* in the casting, and the ends of the trolley wire are passed up through these and bent back over.

7. Fig. 9 shows a suspension provided with an automatic ear. This ear is made in two parts that are hinged together. When *b* is screwed up, the ear *e* clamps the wire, thus holding it firmly without the use of solder. Automatic ears make more or less of a projection, and hence tend to make the trolley wheel jump more than soldered ears. They are, however, easy to put up and are especially useful in places where the location of the hangers may have to be changed.

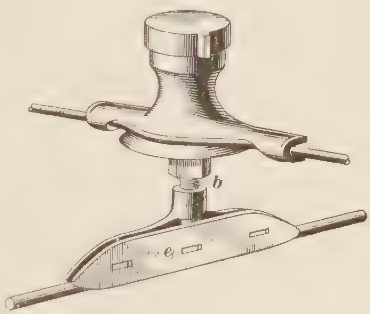


FIG. 9.

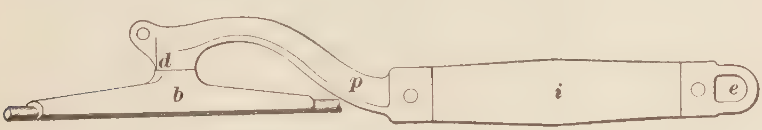


FIG. 10.

8. In rounding a curve, the trolley wire is at first stretched in temporary wire slings and anchored, after which

the hangers or pull-over clamps are attached. For curves of small radius, a form of suspension such as is given in Fig. 10 may be used. The span wire is attached to the eye *e*, which

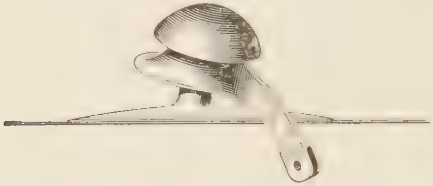


Fig. 11.

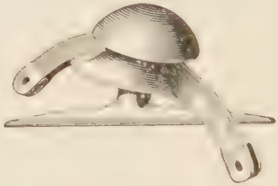


Fig. 12.

is fastened by the insulating piece *i* to the arm *p* carrying the trolley-wire clamp *b* pivoted at *d*. For suspending trolley wires and making repairs on the same, a "tower

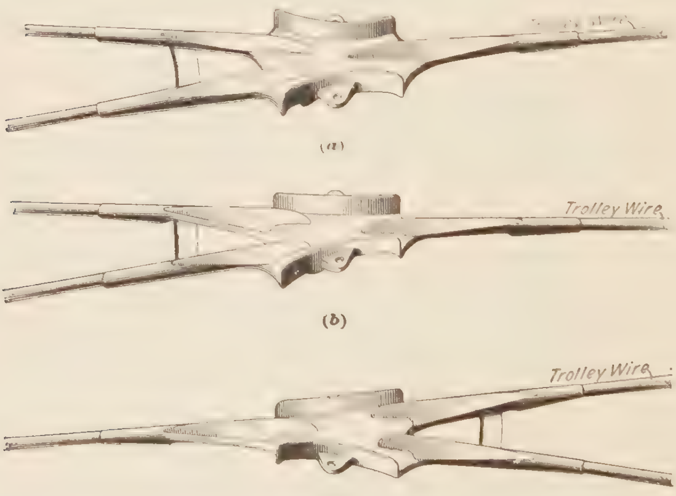


Fig. 13.

wagon" is used, which consists of a platform supported on a wagon at a convenient height for ready access to the wires. This platform is generally so arranged as to project beyond

the wagon, so that the latter may stand clear of the tracks while repairs are in progress and not interfere with regular traffic. When not in use, the platform may be lowered to the wagon by means of a winch.

Fig. 11 shows a single-curve suspension or pull-off. Fig. 12 shows a double-curve suspension.

9. Branch Lines and Curves.—At the point where one line branches from another, overhead switches, or **frogs**, are used to guide the trolley wheel from one wire to the other. Fig. 13 (*a*) shows the under side of a simple

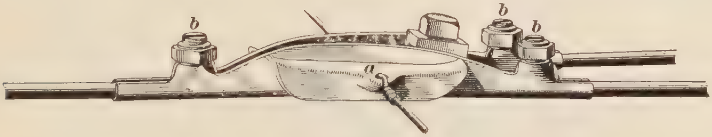


Fig. 14.

two-way V frog of a type that is largely used. (*b*) is a right-hand frog and (*c*) a left-hand frog. In these frogs the trolley wire is soldered into the ears. Fig. 14 shows a V frog in its natural position. In this case, the trolley wire is held by clamps *b*, *b*, *b* and no solder is necessary. The span wire is attached to ears *a*.

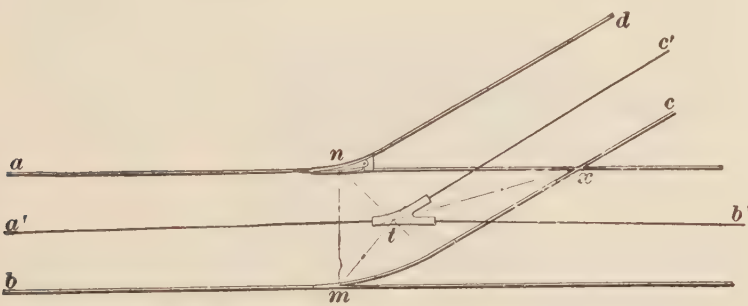


Fig. 15.

10. It is necessary that frogs be placed correctly with relation to the track, and mechanical fastenings for the wires are therefore desirable, because they allow the frog to be adjusted to the position giving the best results. The

satisfaction that any frog will give depends a great deal on how it is put up. If put up level, the trolley is very likely to follow the same direction as the car, but if allowed to sag down on one side, it will be a never-ceasing source of trouble, due to its throwing the trolley wheel off the wire. The position for the frog may be found by the method shown in Fig. 15, where a and b are the main-line tracks, c and d the branch-line tracks, $a' b'$ the main trolley wire, and $t c'$ the branch trolley wire. The center of the triangle $n x m$ will be at a point t where the lines bisecting each angle meet, and this determines the position of the frog. It will be a little removed from the center lines of the tracks.

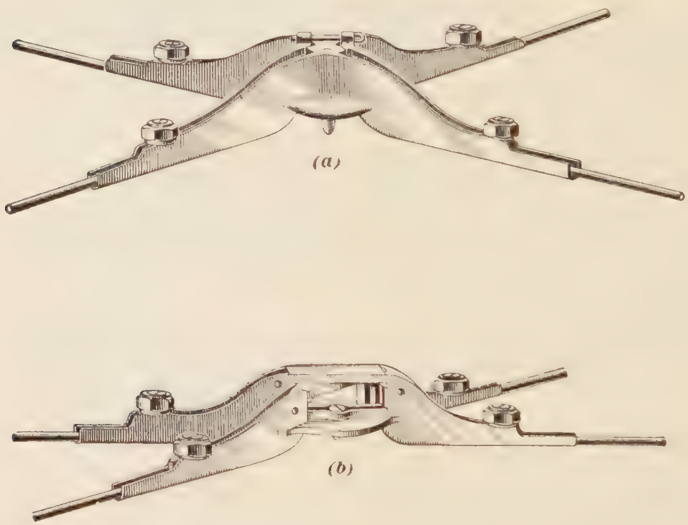


FIG. 16.

11. Cross-Overs.—At the point of intersection of two trolley lines, a device called a **cross-over** is used. Fig. 16 shows two common forms of cross-overs; (a) is used where the two lines cross at right angles, (b) where they cross at an acute angle. Where two lines meet at an angle that is only slightly oblique, it is very often the practice to offset one of the tracks just before the meeting point is reached

so that standard right-angled crossings can be used both in the line and in the track. Where the intersecting trolley

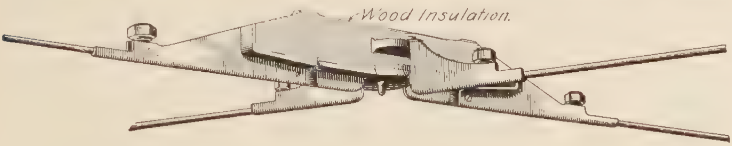


FIG. 17.

wires belong to different companies, it is necessary to insulate the wires from each other. In such a case, a special insulating trolley crossing, Fig. 17, must be used.

12. Section Insulators.—Section insulators are used at the junction of two divisions that are fed by separate feeders

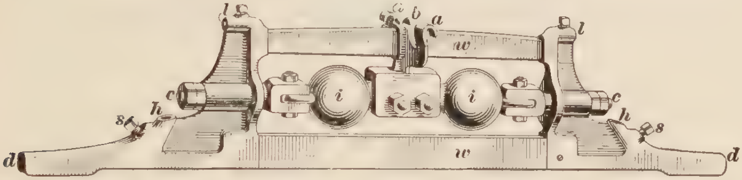


FIG. 18.

from the power house. These section insulators are commonly known as **line circuit-breakers** or simply **line breakers.** One form of line breaker is shown in Fig. 18.

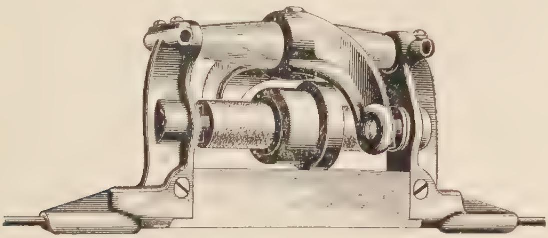


FIG. 19.

The direct line of the trolley wire is unbroken, allowing the trolley wheel to run smoothly across the insulator. The span wire is in one piece between the poles, and is slipped

under the hooks *a*, *a* and over the notch at *b*. A double strain insulator *i*, *i* and bolts *c*, *c* hold the parts together against the pull of the trolley wires from the two sections which pass under the clips *d*, *d* at each end, through the holes *h*, *h*, and are held by the setscrews *s*, *s*. The end castings are provided with lugs *l*, *l* and setscrews, by which connection may be made to the feeders. Distance pieces of wood, well filled to prevent absorption of moisture, are inserted at *w*. Figs. 19 and 20 show two other styles of section insulators or line breakers that have proved satisfactory.

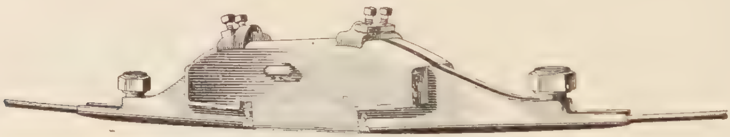


FIG. 20.

13. The main requirements for line devices of any kind are simplicity, durability, and strength. There is no place on the road where appliances are subjected to as violent knocks as they are on the line when struck by a pole that flies off under a tension of 20 or 25 pounds with the car going 20 or 30 miles an hour. Where the device has an insulator, this must be effective; for while the leakage current over one may be small, hundreds of them in multiple will amount to considerable. Every line should be subjected to a constant and careful inspection, and as soon as a fault begins to assert itself, it should be remedied at once.

14. Wire Splicing.—The feeders, if they are not in the form of large cables, are usually joined by using the ordinary Western Union joint, Fig. 21. A solution of rosin in alcohol makes a good flux for soldering such joints, as it does not corrode the wire. Large feeder cables may be joined either by weaving

FIG. 21.

the strands together and soldering or else by using a copper sleeve and thoroughly soldering it on the cable ends. Another recent and effective method of joining cables is to slip a heavy copper sleeve over the joint and then subject this sleeve to very heavy pressure by means of a special portable hydraulic press. All overhead wires after being spliced should be thoroughly taped, so as to provide an insulation at least equal to the covering on the wire.

15. Splicing Trolley Wires.—When a trolley wire is spliced, the joint has to be mechanically strong, because there is considerable strain on the wire; also, the joint must be made to offer as little obstruction as possible to the passage of the trolley wheel. This last requirement, of course, precludes the use of the style of joint shown in Fig. 21. One of the most common methods of splicing trolley wire is by means of a tapered brass sleeve, Fig. 22. The wires go in at each end of the connector and are bent up through the openings *a*, *a*. The remaining space is then poured full of melted solder and the ends of the wire

FIG. 22.

trimmed off. This connector has given good service. The splicing ear shown previously in Fig. 8 (*d*) represents another method of splicing trolley wire. The general idea is the same as that used in the tubular trolley connector, except that it must be used at a point of support as indicated by the lug for attaching to the hanger. The ends of the wire to be spliced go into the ear at the ends, pass up through the holes *h*, *h*, and are turned back and trimmed off. The fins on the lower edge of the ear are clinched and the whole is then sweated with solder and cleaned off. Splicing ears do not always call for the use of solder; in some of them the wire is held by means of screw clamps.

Another style of joint, known as the **scarf joint**, is shown in Fig. 23. It should be at least 6 inches long. It is made

by scarfing the ends of the two wires to be spliced until the two, when laid in lap, are the same size as a single wire. The ends are well cleaned and are laid together and

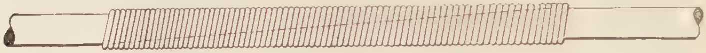


FIG. 23.

wrapped with tinned binding wire. The whole length of the joint is then filled in with solder, the ends of the trolley wire being held firmly during the process by means of a screw clamp.

16. Feeder Insulators.—Heavy glass insulators similar to those previously described may be used for supporting feeders of ordinary size. In the case of large feeders, however, the strain is very great and glass insulators are liable to crack. This is especially the case at curves, where the strain on the insulator may be very heavy.

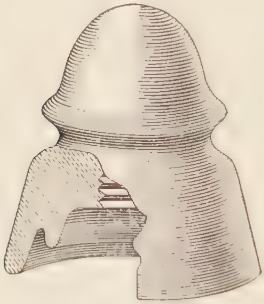


FIG. 24.

FIG. 25.

FIG. 26.

Where the heavy feeder cable subjects the pole insulator to a side strain, as at corners and curves, insulators of composition material, such as molded mica, are used, because this material is tougher than glass and does not crack under the strain. Fig. 24 shows one of these insulators having a groove large enough to take a cable up to 500,000 circular mils cross-section. Fig. 25 shows another style of heavy feeder insulator, the top of which is made of bronze and the lower part of molded insulation. The feeder

rests in the groove and is held in place by the screw cap *a*. Fig. 26 shows still another style, in which the cable also rests in a groove on top, but is held in position by means of a tie-wire.

17. Connecting Feeders to Trolley Wire.—Fig. 27 shows one method of tapping the feeder to the trolley wire. In this case, a hard-drawn copper span wire is attached to

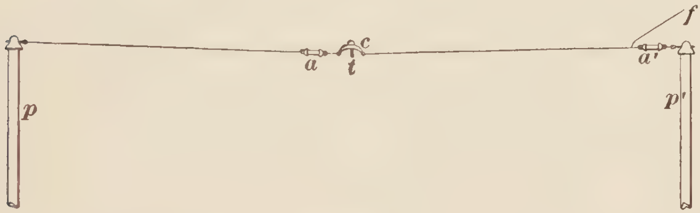


FIG. 27.

a non-insulating hanger *c* that carries the trolley wire *t*. At one end of the span wire, a tap *f* connecting to the feeder is joined on. Strain insulators *a*, *a'* are introduced, as shown, in order to insulate the live parts from the poles.

Fig. 28 shows a second and perhaps a better way of attaching the feeder to the trolley wire. The regular steel span wire is used to support the trolley wire by means of the hangers *e*, *e'*; supported on the same pole, but above

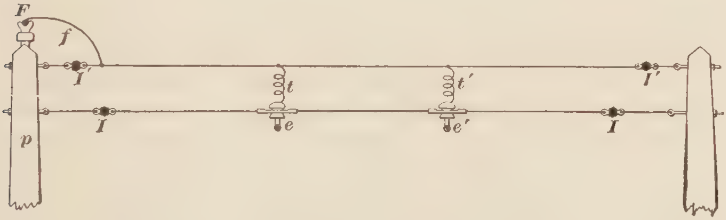


FIG. 28.

the trolley span wire, is a copper wire strung between strain insulators *I'*, *I'*. The feeder *F*, carried on top of the pole *p*, taps into this wire by means of tap *f* inside of the strain insulator. By means of pigtails *t*, *t'* the wire connects to the trolley hangers *e*, *e'*.

18. Underground Distribution.—In large cities where overhead wires are not allowed, the feeders from the station to the different parts of the system have to be run underground, even though the authorities may allow the trolley wire to be strung overhead. Under such circumstances the feeders are in the form of lead-covered cables and are run in underground conduits. The construction is similar to that already described for light and power distribution. Manholes are provided at intersecting points, so that the cables may be reached at any time for repair or inspection. Taps to the trolley wire are run up the poles, and the current is thus conveyed from the station to the trolley wire without large and unsightly feeders being in evidence.

LINE AND TRACK CALCULATIONS.

FEEDERS AND RAIL RETURN.

19. Economical Use of Feeders.—The general methods of calculating the size of line wires to deliver a given amount of power over a given distance have already been taken up. These rules also apply in a general way to the calculation of feeders for electric railways, but there are a number of special points that must be considered.

There is no problem involving as little prospect of ever having general rules laid down to cover all cases and all conditions as the problem of calculating the most economical amount of copper to install and the best method of disposing that copper to meet the requirements of a given street-railway service. It is true that the present practice of dividing the line into insulated sections has, to a certain extent, simplified the work of calculation, because each section can be considered as an independent line governed by its own local conditions of load. If these conditions of load could in any case be laid down with certainty, the problem for any particular case would be solved; but once solved for

that particular case, the solution would be of little use to the engineer for application to other cases, because it is almost impossible to find any two roads or even any two sections of the same road that call for the same conditions of load, and, therefore, for the same distribution of copper. The design of the copper circuit is to a great extent the discreet combination of approximation, experience, and calculation. The calculation is easy, but the guesswork or approximation is rendered difficult by the variation of the load both in magnitude and position. It very often varies from zero to a maximum in a few seconds. During one part of the day the heaviest load might be on one part of the line and later in the day it might be on a section several miles away. Again, there may take place gradually a general shifting of the load more serious than a daily or weekly shift, due, possibly, to changes of attractions from one end of the line to the other, by a shift in the field of suburban improvements. Though overhead work may be installed under a design that meets satisfactorily almost every requirement of the present service, subsequent changes, such as the development of suburban property, may throw the system completely out of balance. The only thing to do then is to go over the work again and put copper where it is needed. But it is now a well-known fact that in promiscuously putting up copper, although it may be placed with good judgment from an electrical point of view and successfully fulfil its mission of raising the voltage to its normal value at the desired point, yet it can be put up at a net loss to the company. Copper is expensive, and in the effort to lessen the loss in the line, it is an easy matter to get so much copper strung that a condition arises where the money invested in copper would, if put out at interest in some other channel of business, pay the investors better than it does in the shape of feeder wire.

20. The conditions that confront the engineer, then, when he proposes to improve the service by stringing more feeders are as follows: By putting up more feeders and

raising the voltage, a certain amount of energy is saved by doing away with some of the line loss, and the amount of this saving in watts or horsepower can be approximately calculated. By knowing what it costs to produce a unit of energy at the power house, the direct saving effected by the increase of copper can be at once obtained, and by knowing the cost of the additional copper installed, including the cost of construction, the interest on the cost of the copper may be computed. If the interest on this cost for one year proves to be more than the money value of the energy saved by the addition of the copper, it is being installed at a loss to the company. If it proves to be less, the addition of the copper is an economy. The rule that it pays to install more copper to raise the voltage, if the cost of the watts saved in one year exceeds a year's interest on the cost of the additional copper put up, is one that should always be kept in mind. It must not be forgotten, however, that the above limiting condition expressed in the form of an equation (interest on the cost = value of energy saved) does not include all the elements that modify the equation. When the feeding system is improved, it brings about a saving in a direct way; it makes the loss in the line less, and it brings about a saving in an indirect way that is just as important; for, by keeping up the voltage and thereby increasing the efficiency and speed at which the cars run, it not only decreases the number of cars necessary to conform to the conditions of a certain time table, but by improving the service, it attracts travel, especially in cases where there is a competing road. Even in cases where there is no competing road, an improvement in the service draws travel. Calling Q the interest on the cost, W the value of the energy saved, and S the money returned per year as a result of the raising of the E. M. F. by the additional copper, the modified equation will read (the present one reads $Q = W$) $Q = S + W$. This equation is more in favor of the added copper and it conforms more to the true state of affairs.

There must be a distinction made between the two conditions where the feed copper is working at an actual loss to the company and where it is working at a less economy than some other means of raising the voltage. The modified equation does not involve the question as to whether the additional copper is working at a less economy than some other means of raising the voltage, but it merely involves the important question as to whether it is working at a loss or not. The general limiting condition as expressed in the original equation, $Q = W$, might be generally true, but in some cases, when it comes to installing the alternative methods of raising the E. M. F., it would be found that any of these methods, on account of the local conditions or on account of the condition of the company, would be practically impossible. From this general discussion it can be seen that, when laying out the overhead work for any electric-railway system, future extensions should always be kept in mind if there is any prospect at all of such extensions being put in.

21. Division of the Overhead Work.—The overhead construction on an electric road may be divided into three main parts: the **feeders**, the **trolley wire**, and the **ground return.** The feeders require the greatest outlay of copper. At present, the common practice is to divide the trolley wire into sections, each fed by its own feeder, and under these circumstances the trolley wire does not help very greatly towards the general conductivity of the system. With the sectional system of distribution, the drop in the trolley wire, under ordinary circumstances, is not very great. If a car, however heavily it may be loaded, is just under the point where the feed wire connects to the trolley wire, there will be no loss in the trolley wire due to that car, because, as far as that car is concerned, the trolley wire is not in use; but as the car moves away from the tap, the amount of the trolley wire in use increases in direct proportion to the distance of the car from the tap. If the trolley wire is of the liberal dimensions advocated at the present

time for mechanical reasons, the drop in it, even when the car has reached a point near the end of a section, is not very large, because the sections are comparatively short. Assuming that there is a single feeder tap, which is not often the case, to each section of trolley wire, and further assuming that the load on the section is evenly distributed, the trolley wire will be called on to carry but one-half of the feeder current. If, for some reason or other, all the cars happen to be bunched on one side of the single tap, the trolley wire will have to carry all of the current that the feed wire does, and the drop will be excessive, because the trolley wire is not designed to meet such abnormal requirements of load; nor would it be economical to so design it, for the excessive load is only temporary.

The trolley wire now put up is very much heavier than that used on the older roads, and it will carry quite a large current for moderate distances without an excessive drop. When the early roads were installed, feeders had not come into extended use; consequently, the small wire had to carry the whole load wherever it happened to be concentrated, and the drop was therefore excessive. It must be remembered, however, that the loads carried then were not nearly as heavy as those carried now, because the cars and motors were much smaller.

22. The Ground Return.—The next element to be considered is the ground return. Some roads, principally conduit or slot roads, do not use the ground return. They are called **metallic-return** roads; i. e., they have copper wires to take the current out to the motors and wires to bring it back to the power station. Such roads have their advantages and their disadvantages. The principal advantage lies in the fact that with a metallic return, it takes two grounds to tie up the road, and these grounds must be on opposite sides of the system. As there are means of detecting a ground as soon as it occurs, it can be removed before the next one takes place. This system is

well adapted to slot roads, where the source of trouble is not so easy to get at as it is on open work.

On overhead work, it is almost the invariable rule to use the rails to bring the current back to the power house. The rail itself, on account of its large cross-section, has large current-carrying capacity, but at the joints where the rails come together, the conductivity is in time greatly impaired by rust, so that extra means must be provided for carrying the current around the joint. The means provided are pieces of copper connecting the rails together and called **bonds.** At one time the earth was for the most part relied on to conduct the current back to the power house. On account of its great size and cross-section, it was assumed that its resistance was zero and that, therefore, no drop in

FIG. 29.

voltage would take place through it. Under this assumption the conductivity of the rails was neglected; in some cases they were bonded with a small iron wire and in many more cases they were not bonded at all. In course of time the idea that the earth offered a return circuit of zero resistance was abandoned, and it was further found that most of the losses in transmission were due to a poor return circuit. As a matter of fact, the earth as a conductor cannot be relied on in railway work at all. Even admitting that it were a good conductor, standard track construction in cities is such that it would be almost impossible for the current to get from the rail to the earth through the many poor conducting mediums, such as ties, concrete, etc., interposed directly in its path. As an example, to show how little the earth can be relied on as a conductor and how erratic any calculations in regard to it might be, take the case shown in Fig. 29, where A, B, and C are three points in a straight line. It has been experimentally proved that the resistance of the earth between points A and C is just as liable to be less as it is to be more than that between A and B. The

resistance between any two earth points is found to be greatly influenced by any gas or water pipes that may be near them; it is also influenced by the way in which the earth's strata may lie. The fact has also been proved that the resistance between any two points depends more on the area of contact between the earth plates and the earth than it does on the distance between the earth plates. As a result of the information gained from such experiments and as a result of the practical good secured in many cases by not only properly bonding the rails together, but also by connecting the bonds together by means of a bare copper wire zigzagging down the center of the track throughout its whole length, it has come to be the rule to ignore the carrying capacity of the earth altogether and to rely on that of the rails, the copper bonds, and return copper conductors. In fact, everything possible is done to keep the current out of the earth; if, after leaving the rail, it would confine itself to the earth, no harm would be done; but in its efforts to get a low-resistance path, it goes into any pipes or cable sheaths that may be in its way, and where it leaves them to go back to the rail or station, it eats the metal away. Under the proper conditions, this process, known as **electrolysis,** will eat a hole in an iron pipe in a year. Very naturally, the gas and water companies object to having their property ruined in this way, and in some countries have brought about legislation requiring that at no place on the system shall there be over a certain drop between the rail and neighboring pipes. There have been several means devised for combating the electrolytic effect of the leakage current in an electric railway with a rail return.

23. On an electric road it is not as essential that the E. M. F. should be kept constant at all times as it is that it should be kept up to or above its normal value at all points on the road. To keep the E. M. F. constant at all points is impossible; to keep it near the normal value is possible, if the return circuit is good and the trolley wire is fed as it should be.

CALCULATION OF TRACK RESISTANCE.

24. Resistance of Mild Steel.—The resistance of mild steel, such as rails are made of, varies considerably with the composition of the metal. For purposes of calculation, we will take the specific resistance of mild steel as 7 times that of copper. This is a fair average value, but some of the harder varieties of steel would run considerably above this. If we take the resistance as 7 times that of copper and the resistance of 1 mil-foot of copper as 10.8 ohms, then the resistance of 1 foot of mild-steel wire 1 mil in diameter would be $10.8 \times 7 = 75.6$ ohms.

25. Relation Between Weight of Rail and Cross-Sectional Area.—Rails are always designated by the number of pounds that they weigh per yard. Thus, a rail weighing 60 pounds per yard is known as a 60-pound rail; one weighing 80 pounds per yard as an 80-pound rail, and so on. The resistance of a rail, of course, depends on its sectional area, so that it is convenient to bear in mind the relation between the weight in pounds per yard and the cross-sectional area in square inches. Fortunately, this relation is a very simple one, because it so happens that the weight in pounds per yard divided by 10 gives the cross-sectional area quite exactly. For example, an 80-pound rail would have a cross-section of $\frac{80}{10} = 8$ square inches. We may write

$$A = \frac{W}{10}, \qquad \textbf{(1.)}$$

where A = area of rail section in square inches;
W = weight of rail in pounds per yard.

Rule.—*To find the area of cross-section of a rail, divide the weight in pounds per yard by 10.*

Rails now in use run from 35 pounds (too light for a car having motors on it) to 100 pounds per yard (an extra heavy steam rail). The rails most commonly employed run from 60 to 80 pounds per yard, and the general tendency is to increase the weight of rails.

26. Relation Between Weight of Rail and Resistance.—A copper bar having 1 square inch cross-section would have an area of 1,273,236 circular mils. The resistance of 1 mil-foot of copper is 10.8 ohms; hence the resistance of a bar of copper 1 square inch in cross-section and 1 foot long would be $\frac{10.8}{1,273,236}$ and a bar 1 yard long would have a resistance of $\frac{10.8 \times 3}{1,273,236}$ ohms. If we take the resistance of mild steel as 7 times that of copper, the resistance of a bar of mild steel of 1 square inch in cross-section and 1 yard long would be $\frac{10.8 \times 3 \times 7}{1,273,236}$ ohms. A bar having an area of 2 square inches would have $\frac{1}{2}$ this resistance, and the resistance of 1 yard of a rail having a cross-sectional area of A square inches would be

$$R_y = \frac{10.8 \times 3 \times 7}{1,273,236 \times A} = \frac{.000178}{A}, \qquad (2.)$$

where R_y = resistance per yard of rail;

A = area of cross-section of rail in square inches.

Rule.—*The resistance in ohms of 1 yard of mild-steel rail is equal to .000178 divided by the area of cross-section of the rail in square inches.*

27. We can also express the resistance in terms of the weight per yard.

$$A = \frac{W}{10};$$

hence,

$$R_y = \frac{.000178}{\frac{W}{10}} = \frac{.00178}{W}, \qquad (3.)$$

where R_y = resistance per yard;

W = weight per yard.

Rule.—*The resistance in ohms of 1 yard of mild-steel rail is equal to .00178 divided by the weight in pounds per yard.*

Sometimes it is more convenient to have the resistance expressed in terms of 1,000 feet of rail. 1,000 feet $= \frac{1000}{3}$ yards; hence,

$$R_m = \frac{.00178 \times \frac{1,000}{3}}{W} = \frac{.6}{W}, \text{ approximately,} \qquad \textbf{(4.)}$$

where R_m = resistance per 1,000 feet of rail;
W = weight per yard.

Rule.—*The resistance in ohms of 1,000 feet of single rail, not including joints, is equal to .6 divided by the weight in pounds per yard.*

Formula **4** therefore gives the resistance of 1,000 feet of single rail, not including joints. For two rails in parallel, as on a single track, the resistance per 1,000 feet would be $\frac{.3}{W}$, approximately, and for a double track it would be $\frac{1}{4}$ that given by formula **4,** or $\frac{.15}{W}$.

Example.—What is the resistance, not including joints, of 2 miles of single track laid with 60-pound rails?

Solution.—Since there are two rails in parallel, the resistance per 1,000 feet will be $R_m = \frac{.3}{W}$ and the resistance of two miles will be

$$R = \frac{.3}{60} \times \frac{5,280 \times 2}{1,000} = .0528 \text{ ohm. Ans.}$$

28. In the case of an electrically welded rail, there is really no joint, electrically speaking, as the rail becomes continuous. Owing to the fact that, as a rule, extra pieces of metal are used in making the weld, the welded part may actually have a greater cross-section than the rail itself. In such a case, the above formulas include the joints; but for ordinary fish-plate joints they do not include the joint resistance.

RAIL JOINTS AND BONDS.

29. General Remarks on Rail Joints.—There is no feature about electric-railway construction that calls for more care and attention than the rail joints. It is not such a hard matter to get a joint that is mechanically good, but it seems to be a very difficult matter to get one that is electrically so, and even if it is good to begin with, it is a still harder matter to keep it in that condition. After a joint is once made electrically good, the only thing to be done is to watch it and test it at frequent intervals, to see that it is mechanically firm and that its resistance is as low as it should be, for the permanency of a joint as a conductor depends as much on its mechanical condition as it does on anything else. When a track is first laid and the rails and fish-plates are new, the joints carry a current satisfactorily, but in course of time the parts become rusty, and rust will scarcely conduct the current at all. The result is that a single joint may at length have more resistance than several hundred feet of the rail itself; there are even cases on record where a joint, on account of looseness and rust, refused to pass the current at all. To do away with all chances of such a condition arising, it is the practice to use bond wires to electrically connect the ends of abutting rails together. *Bond wires*, or *bonds*, are simply copper wires or bars provided with terminals to be driven into holes drilled near the ends of abutting rails. There are various ideas in use for improving the amount and quality of the surface contact between the bond and the rail. If, however, the joint is allowed to run down mechanically and become loose, it will be a matter of only a short while until its electrical conductivity will be greatly impaired or even altogether destroyed, for the continual vibration is almost sure to work the bond loose in time. It is a source of wonder how in the earliest days of electric railroading some of the roads could operate their cars under the conditions that were later found to exist in the rail return. The rail return is just as important a part of the circuit and can cause just as much loss of energy as the overhead wires.

In most cases, as soon as the voltage on the line begins to

fall below normal, the first thing thought of is to put up more overhead feeders. Sometimes such feeders will do a great deal of good, but very often they do not help matters much. If the rail return is in good condition, the chances are that the addition of line feeders will help the situation; but if the rail return is in very bad shape—the joints loose and the bond wires loose or broken—overhead feeders will be a waste of money that should be spent in perfecting the bonds and joints. Increasing the copper in the line work when the track return is the place that should be fixed, amounts to about the same thing as trying to make water run more freely through a series of pipes by carefully cleaning the inside of some of the pipes when perhaps the others are choked with rubbish. Before putting up any more line feeders to raise the voltage at any given point on the line, the resistance of the feeders already feeding that point and the resistance of the rail return from that point to the power house should be carefully measured and the two compared. If they prove to be about the same, an improvement in either place will do the work. If the rail return proves to be in comparatively good shape, any further improvement in that place will not effect the desired change, because the loss is in the feeder, and it is therefore the feeder part of the circuit that needs attention. On the other hand, if the resistance of the rail return proves to be much higher than that of the feed circuit, the rail return is the place to be improved, and money put in feed wires is thrown away.

30. Distribution of Resistance in the Rail Return. Let us now take 1,000 feet of single-rail return and see how the resistance is divided between the rails, the bond wires, and the bond-wire contacts. Before this can be done, some weight in pounds per yard must be assumed for the rail and some definite size of bond wire must be selected. As the practice at present seems to be towards the use of a heavy rail, 80 pounds per yard might be taken as a fair average. As a rail bond should never be any smaller than a No. 0000 wire, whatever may be the weight of the rails employed, a No. 0000

bond wire will be taken in the following calculations. Rails in ordinary use are about 30 feet long; hence there will be ($\frac{1000}{30} = 33$) 33 rails in 1,000 feet of single rail. From the formula for single rail, we have $R_m = \frac{.6}{80} = .0075$ ohm per 1,000 feet. The resistance of 1,000 feet of 80-pound rail, neglecting the joints, is .0075 ohm. There is a bond wire to every rail, and every bond wire has two contact places. The bond wires need not average more than 1 foot in length, and there will be 33 bond wires in 1,000 feet of single rail. 1,000 feet of No. 0000 copper wire measures roughly .05 ohm; the resistance of one bond wire (1 foot) is $\frac{.05}{1000} = .00005$ ohm, and the resistance of 33 bond wires is $33 \times .00005 = .0016$ ohm, approximately. The resistance of the contact between the bond and the rail varies a great deal, depending on the area and quality of the surfaces exposed to each other; these in turn depend on the kind of bond-wire contact used and on the skill and care with which it is installed. Bond-wire contact resistances, under fair conditions even, vary from .000005 to .0008 ohm, so that it is safe to assume for purposes of calculation a value of .0002 ohm, as proposed by Dr. Louis Bell.* On a well-bonded road, the resistance per bond would not run as high as this, but on some roads it would run a great deal higher. As there are 33 bond wires per 1,000 feet and as each bond has two contacts, there will be 66 bond-wire contacts per 1,000 feet. With a resistance of .0002 ohm per contact, this brings the total bond-contact resistances per 1,000 feet up to $66 \times .0002 = .0132$ ohm.

Collecting the three values determined above, we have 80-pound rail resistance for 1,000 feet = .0075 ohm; resistance for 33 bond wires in the 1,000 feet of rail = .0016 ohm; resistance of the 66 bond-wire contacts = .0132 ohm. This makes the total resistance of the 1,000 feet of single rail amount to $.0075 + .0016 + .0132 = .0223$ ohm. This comparison shows that the bond wires and the contacts are

* Power Distribution for Electric Railroads by Dr. Louis Bell.

responsible for two-thirds of the entire resistance of the 1,000 feet of single rail; so the fact that the rail has a bonded joint every 30 feet multiplies the resistance of the rail return by 3. By installing two bond wires instead of one, the resistance due to joints would be halved, making the total resistance of the 1,000 feet of single-rail return $.0075 + \frac{.0016 + .0132}{2} = .0149$ ohm. This reduces the total single-rail resistance per 1,000 feet to a value only twice what it would be if there were no joints or reduces it $33\frac{1}{3}$ per cent. The best method of reducing the resistance due to joints is to use a 60-foot rail instead of the standard 30-foot rail. This construction has the advantage of not only halving the number of electrical joints, and thereby halving the drop loss due to joints, but by halving the mechanical joints, it halves the pounding that the car has to go through, and in this way saves both the track and the rolling stock. Of course, a 120-foot rail would be much better still, but there is a limit to the length of rail that can be shipped and handled economically. The desirable feature of length pushed to its limit would call for one continuous rail for the whole road. Such a rail could not be rolled or shipped, but perfect continuity of the rail can be obtained by the electrical welding process. Experience has shown that where the rail is embedded in paving, the trouble due to expansion and contraction cannot exert itself. The paving prevents sudden changes in the temperature of the rails and also holds them so that they cannot move laterally.

The value .0223 ohm, it must be remembered, is the resistance of 1,000 feet of single rail including the joints. The resistance per 1,000 feet of single track, or two rails, would be one-half of this, .0111 ohm. The resistance per 1,000 feet of double track would be about .0056 ohm. It is easily seen that on a double-track road, with heavy rails and with the joints all welded, the resistance of the rail return might be brought very nearly down to a value where it could be ignored altogether in comparison with that of the overhead work; but as such an ideal condition of things would be

very unusual, we will, for purposes of calculation, assume that the track is well bonded and that the resistance per 1,000 feet of single track is approximately .0111 ohm.

31. Bonds.—Rail bonds are made in a great many different styles, the differences between some of them being very slight. They are all designed, however, to get the best possible contact between the rail and the bond, also to withstand the tendency to break off under the action of the continuous vibration and pounding to which the joints are subjected when the cars pass over them. There are so many different kinds of rail bonds on the market that to describe them all would be out of the question, but it might be well to describe briefly several types, the construction of which brings them on the safe side of the 1 foot of No. 0000 wire assumed in the calculations.

32. Fig. 30 shows one form of bond; the conducting part *a* of this bond is flexible, being made up of a number of small flattened wires cast-welded into the terminals that attach to the rail. To install the bond, the fish-plate must be removed and two holes drilled in the rail to fit the plug portion of the terminal. The plugs are then pressed into the

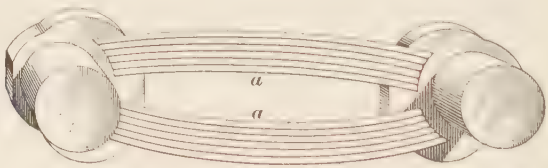


FIG. 30.

holes in the rails by means of a special press that forces them home until they not only fill the holes snug, but their heads also flatten over on the opposite side of the rail, thereby giving greater area of contact between the bond and the rail. The fish-plate is then screwed back into place. This bond belongs to what is known as the **protected** class, as the fish-plate not only protects it from mechanical injury

and the action of the weather, but also from the attacks of copper thieves.

Fig. 31 shows another type of protected bond, known as the *ball bond*, because a small steel ball is used to expand the contact between this bond terminal and the rail. As

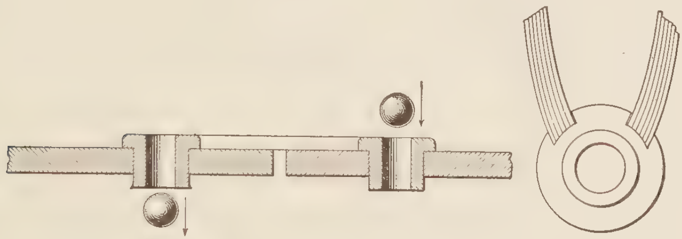


FIG. 31.

shown in the figure, the plug part of the terminal that goes into the rail is hollow. To fix the bond to the rail, the plug is slipped into the hole and a small steel ball is then driven

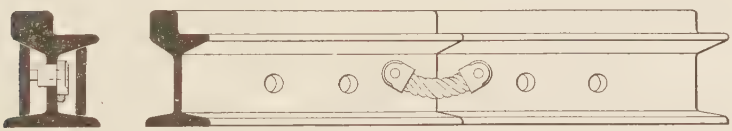


FIG. 32.

through the hole in the plug; this serves to expand the plug into the sides of the iron hole and thus secures a good contact. If the first ball forced in goes through too

FIG. 33.

freely, a little larger one is used. Fig. 32 shows another form of protected bond. This bond has a stranded conductor, but solid terminals, and the bond itself is quite short.

33. Fig. 33 shows a style of bond known as the **plastic** bond from the fact that the medium of contact is a paste or amalgam and is therefore plastic. This bond has the unique feature that the fish-plate itself is used as the bond proper, the plastic part merely insuring that there shall be a good contact between the fish-plate and the rails. A piece of cork holds the plastic compound in position near the side of the rails. The surface of the plate and rail is brightened before the plastic device is put in place, and as the contact surfaces are thereafter protected by the plastic compound, which remains soft, air and water are kept from the joints and rusting cannot take place. The idea involved in applying the plastic device can be more clearly seen in Fig. 34, which shows the method of its application to the bonding of old rails. In this case, a hole must be bored through the fish-plate and into the rail. The amalgam is shown at *b*. The above bonds have not been selected with the idea of putting forth the merits of the best ones to use, for there are many others that, with one or two exceptions, are perhaps just as good as the ones given, but they are given to show some of the many ways used to attach the bonds to the rails. There are bonds with threaded shanks, held in place by nuts and jamb nuts; others depend on pins; and others, again, have their ends welded or brazed to the rail.

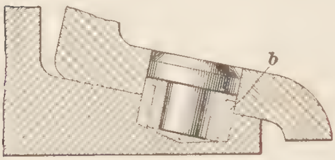


FIG. 34.

34. Disposal of the Bonds.—Having selected the kind of bond to be used in any case, the next question is, how

FIG. 35.

shall they be disposed, and is it necessary to help them in any way by supplementary wires? Fig. 35 shows the style of bonding used in the early days of electric railways. In

this figure, A, A, A, A are the rails and B, B, B, B the bond wires. Each rail is connected to the one abutting it. With the exception, perhaps, of the ends, the two lines of rail are not connected together; so that if a bond wire breaks and at the same time the iron joint happens to be very bad, the rail return becomes almost useless beyond the break as far as that line of rail is concerned.

FIG. 36.

If the bond wires are of ample size and are so installed that they can be relied on not to break, the style of bonding shown in Fig. 35 is good enough for all practical purposes; but, unfortunately, there can be no certainty that the bond wires will remain in as good a state as they are when they are put in. In spite of all precautions, they will break or become loose, and some steps must be taken to lessen the bad effects of such a mishap. Fig. 36 shows the first step taken in this direction. In this case, the nearest opposite bond wires are tied together with a cross wire, so that the

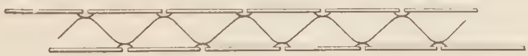


FIG. 37.

rail return cannot be entirely ruptured unless both of the bond wires tied together give way. The chances of a complete break in the return circuit of either rail are lessened by the fact that the rails are thus tied together at frequent intervals. To still further insure the continuity of the rail return and to protect it against the evils of faulty bond wires, the scheme shown in Fig. 37 is sometimes adopted. In this case, not only are the rails bonded together as usual, but all the bond wires are connected together by means of a bare copper wire that zigzags down the track from one bond wire to the other. This auxiliary wire carries the current over any breaks that might occur and makes it almost impossible for such a thing as a dead rail to develop.

Besides this, it actually serves as an auxiliary wire in multiple with the rails. Of course, such a wire, since it is often no larger than a No. 6 B. & S., has a very small capacity compared with that of the rails themselves, as has been shown by the fact that in several instances the continuity of the rail return has become so bad that this zigzag wire has burned off on account of the large current that it had to carry. With such a construction, however, it is almost impossible for the breaking of several bond wires to seriously interfere with the running of the cars.

On some roads, the ground return is supplemented by an extra ground feeder running along the track, either supported on the poles or buried underground, as shown in Fig. 38. This auxiliary return is tapped to the rails at regular intervals. Such a feeder is especially effective where the road curves, so that the end of the line is much nearer to the power house than the intermediate portions of the line. In cases of this kind, it pays to string a ground

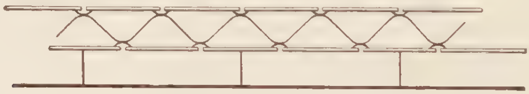


FIG. 38.

feeder across lots to the power house to avoid having the current follow the roundabout path offered by the rails. Where there is a double track, it is customary to bond the two lines of rail together at intervals of 400 or 500 feet. Special care must be taken to do a good, safe job of bonding at all crossings and special work, for it is there that the cars do most of the pounding and the bond wires are most likely to be worked loose or broken. In fact, it is a good idea to duplicate the bonds at such points, for if one breaks, the other still preserves the continuity. All joints between a supplementary ground-return wire and the bond wires should be well soldered, and where the rail-return connection is made at the power house, it should be a metallic one between the rail and the negative bus-bar, and not through the agency of a ground plate alone.

35. In perfecting the rail return, the best rule to keep in mind is to make it as good as it can be made, for even then the chances are that it will not be any too good. In perfecting or improving the rail part of the circuit, there is not the same chance of exceeding the economical limit of investment that there is in the overhead work, because the amount of copper involved is comparatively small. The rails are a necessary part of the equipment, anyway, and if full use can be made of them as conductors, so much the better. If the track is thus used to carry the current, it effects a saving by doing away with the necessity of a solid copper return. Again, where the conditions prescribe that the drop in voltage between the station and the cars be limited to a certain amount, this drop includes the loss in the track return as well as the overhead line, so that if the track resistance is low, the bulk of the drop may be made to take place in the overhead-line work, thus helping to keep down the size of the feeders. In the track circuit there are two or four lines of rails, as the case may be, and each line of rails has carrying capacity for a certain amount of current; none of this carrying capacity should be thrown away by reducing the conductivity of the rails with poor or insufficient bonding.

36. Cast-Welded Joint.—Cast-welding is now frequently resorted to for bonding the rails. It makes a strong joint mechanically, and if the work is properly done, the resistance of the joint may be as low, if not lower, than that of a corresponding length of rail. The ends of the rails are first carefully cleaned by means of a sand blast, and are then held in position by a special clamp that forms a mold around the joint. The cast iron *l*, Fig. 39, is then poured into the mold from a portable cupola. The joint so formed is very stiff

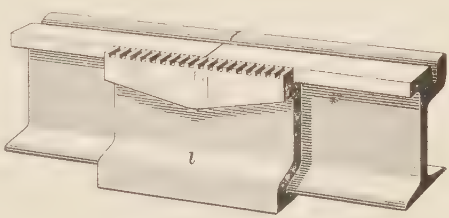


FIG. 39.

and is of high electrical conductivity. The cast iron *l* is approximately 100 pounds in weight and covers the rails for a length of 10 or 12 inches.

37. Electrically Welded Joints.—In this method of joining the rails, the abutting ends are first cleaned and then held by a special arrangement, by means of which they may be pressed together after they have been brought to a welding heat. A heavy current is then sent through the joint until it becomes heated. This current is usually furnished by a special welding transformer that is capable of delivering a very large current at low pressure. This transformer is usually supplied with alternating current that is obtained from a rotary transformer or motor generator, operated by the 500-volt trolley current. The electrically welded joint has a very low electrical resistance if the work is properly done. It is, however, hardly as strong mechanically as the cast-welded joint, unless it is reenforced by side pieces. The cast-welded joint is used more widely than the electrically welded joint, but the great majority of roads use the regular fish-plate joint.

THE TRACK.

38. General Remarks.—There is no class of track work that calls for more care and attention to details than that for a track on which cars equipped with heavy electric motors are to run. There are two general ways of propelling street cars over the road. One way is by means of a force outside of the car itself, as found in the cable road; and the other is by means of a force applied directly to the car axles, as on cars propelled by air, steam, and electric motors. The latter way has the advantage that each car is an independent unit, so that trouble on one does not necessarily interfere with the running of the rest. But, on the other hand, the wear and tear on the track on an axle-driven system is much greater than it is on a cable system. This is due not only to the increased weight of the independent unit

incidental to its carrying all its own driving devices, but to the continual slippage of the wheels and hence grinding effect that takes place under certain conditions. This latter point is proved by the fact that on grades the up-going rail always wears out first, because this is the track on which the most spinning of the wheels takes place. This effect is often noticeable on the head of the rail, even on level track; the rail looks as if some one had gone along with a small emery wheel and ground the rail top into a series of arcs of circles—quite small, it is true, but plainly noticeable. Added to these two features is that of the much higher rate of speed at which self-contained cars run. As a result of all these influences, whenever a horse-car line is converted into an electric line, it is in most cases necessary to change not only the weight and style of the rail used, but the whole roadbed construction. Great care has to be taken to support the joints between the ends of the abutting rails in a thorough and substantial manner, because it is here that the pounding takes place and the greatest wear occurs. An electric road requires the exercise of even more care in the perfection of its track work than any other kind of road, because not only are the rails a part of the electrical circuit in most cases, thus making it necessary that they be electrically continuous from one end of the line to the other, but the life of the overhead work and the rolling stock is indirectly but very largely dependent on the quality of the track.

In order to get the best electrical results out of the rail as a return conductor, the joints should be able to carry a current with as little loss of energy as the same length of the rail itself. There are means provided for securing this condition when the track is new, but no means can be provided for preserving the electrical continuity if the joints are allowed to run down and become loose. If the joints are good and the rail is smooth, there will be no trouble in keeping the trolley pole on the wire, unless there is a defect in the pole or wire itself. Such a trouble would be local and easily remedied. But if the joints are bad, there will be no end of trouble, due to the pole jumping off the wire.

Nothing is harder on trucks and car bodies than a bad track; the pounding and jolting loosen the truck and motor bolts, wreck in course of time the suspension rigging and let the motor down on the pavement; it causes excessive teetering, setting of springs, and breaking of axles; it is hard on the bearings and just as hard on the brushes, with the result that the commutator soon gets in bad shape and troubles from flashing, grounds, and open circuits begin.

39. The kind of roadbed and rail to be used depends on where the road is located. If the soil has a very poor bottom, such as is the case in New Orleans, La., the subwork of the roadbed must be much more substantial than there is any need to be on soil that is firm and lays on a rock bottom, such as is found in New York. Where the proposed road runs through the country, it is the custom to use a **T** rail; in cities, on paved streets, the girder rail is used; but on account of its easy riding qualities and less cost, the trend is towards the use of the **T** rail wherever it is possible.

It is a well-known fact that in sections where the wagon traffic is heavy, the rail gets a great deal of its wear from this traffic. All light and medium vehicles are built to standard gauge to fit the track, and the heavier ones of wider gauge run with one wheel on the rail while the other one cuts a groove alongside of the other rail. To offset any inducement that the rail might naturally offer to wagon traffic, the plan was adopted of so shaping the rail and so bringing the paving up flush with its head, both inside and outside of the track, that there would be very little tendency for the wheels to follow the line of the rail. Wagon traffic takes the path of least resistance; one way, therefore, to lessen the traffic on the rail is to make the paving on both sides of it good.

40. Staggered Joints.—In placing the rails, opinion is divided as to how the joints should be disposed; some engineers are in favor of staggering the joints, while others prefer to put the joints opposite each other. The natural advantage of the broken or staggered plan is that if the

joints are in poor condition, the jolting of the car is not as severe passing over them one side at a time as it is passing over both sides at the same time, as is the case with the joints opposite; on the other hand, when the joints are staggered and are in bad condition, the car, especially if it is a long body on a single truck, acquires a disagreeable side rolling motion, very much like the motion due to a sprung axle. On double-truck cars the effect is not so marked. The general practice is, however, to use staggered joints.

While the importance of making the track as good as possible has been realized for many years, it is only within the last few years that tracks have been constructed to withstand the hard usage to which motor cars subject them. Even high-grade concrete meets with liberal use in the subwork of such roads. The steel cross-tie threatens to take the place of the wooden one, and the old-style tie-rod is giving way to a tie-beam as large as the rail itself.

THE ROADBED.

41. The permanent character of the track as a whole depends greatly on the character of the roadbed; if after the substructure is laid, it gives or swerves in places, everything that rests on it gives and swerves also, so that in course of time the surface of the track becomes undulating and serpentine in outline. Electric roads as far as possible now follow steam-road practice in their roadbed and track work, and for out-of-town work they could not do better. Fig. 40 shows a standard steam-road construction. The same care and exactness that are observed in steam-road construction should be observed in electric railroading, where the train speeds are often almost as high and other conditions just as severe.

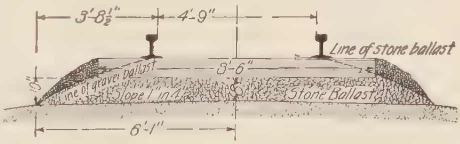


Fig. 40.

42. Methods of Installing Electric Roadbeds.—On suburban electric roads, the steam construction can be followed closely. It frequently happens, however, that electric roads are run in streets that if not already paved will be at some future time, and hence the conditions are somewhat changed. The methods of building electric roads differ so radically that it can be truly said that the only elements of construction in common to all electric roads are the earth and the rails. Some roads have wooden cross-ties, some metal, and others have no cross-ties at all. One road must build an expensive substructure for its roadbed and another, on account of natural conditions, may not have to lay scarcely any roadbed. There can be no better way of bringing out these several points in construction than to take examples of roads on which they occur; but before doing this, we will consider the most common forms of rail in use and the conditions to which they are best adapted.

RAILS.

43. T and Girder Rails.—There are two kinds of rail in common use, the T rail and the girder rail, both of which

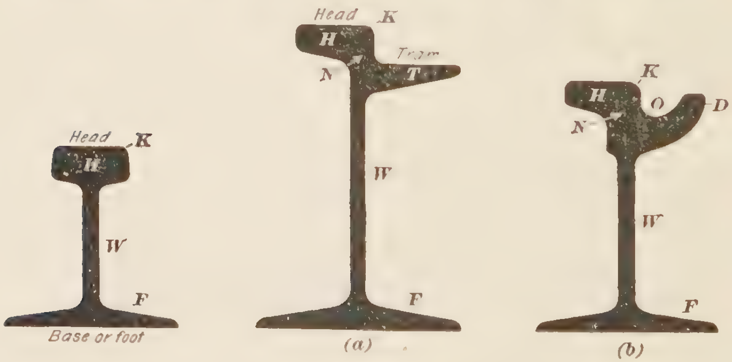


FIG. 41. FIG. 42.

get their names from their general shape. Fig. 41 shows a type of T rail used for cross-country, suburban, elevated,

and underground roads, where the wagon traffic does not have to be considered. *H* is the head, or ball, of the rail, *W* is the web, and *F* is the flange, or foot. A **T** rail is called a center-bearing rail, because the center of the head is directly over the center of the web. Fig. 42 (*a*) and (*b*) shows two types of girder rail; (*a*) is known as a **tram rail** on account of the tram *T* and (*b*) is known as a **grooved rail,** because it has the groove *O*. In Fig. 42 (*a*) and (*b*), *H* is the head; *W*, the web; *F*, the flange, or foot; *N*, the neck; *D*, the lip; and *K*, the gauge line or line that the heel of the gauge touches when gauging the distance apart of the rails. The tram rail is the first in order of invention, and it is still more used than any other type of girder rail.

44. Grooved Rail.—The grooved rail was introduced as a means of diverting wagon traffic from the rail, and in this it has succeeded quite well; but in the earlier forms of grooved rail, it was found to be a source of constant trouble to keep the ice, dirt, and stones out of the groove. The presence of this foreign matter not only increased the power required to run the car, but it also introduced an element of danger, as a small stone could throw the car off the track. In modern grooved rails, however, such as that shown in Fig. 43, this bad feature is very much mitigated by the shape given to the groove. For a given groove, there is always a given shape of car-wheel flange that is best suited to that groove; so that in buying car wheels, due regard must be had for the shape and size of the groove that they are to run in, otherwise there will be excessive wear in the groove and on the wheel flange. A wheel flange must be of a certain depth in order to be safe; if the depth of the groove and the depth of the flange of the wheel are about the same, the least bit of wear in the tread of the wheel will let the weight of the car down on the flange, where it is not intended to be and which will not

FIG. 43.

stand it; if the wheel flanges are deeper than the groove, the wheels cannot be used at all. A track of grooved rail must be gauged to exactness, because it offers two chances for the wheels to bind. If the gauge is too narrow, the outsides of the wheel flanges bind against the heads of the rails; if the rails are too far apart, the insides of the wheel flanges bind against the side of the groove.

45. Standard Track Gauge. — The standard track gauge is 4 feet 8½ inches, as measured by means of a gauge such as that shown in Fig. 44 (*a*). The car wheels are pressed on the axle to 4 feet 8¼ inches by means of a gauge similar to that shown in Fig. 44 (*b*). To apply such a gauge correctly, one end of the gauge should be free to move laterally about 2½ inches, when both of the notches engage the flanges of the two wheels. T rails are much more economical from the operating point of view than girder rails, because however much the tread of the wheel may wear down or be ground down there is nothing for the flange of the wheel to ride on.

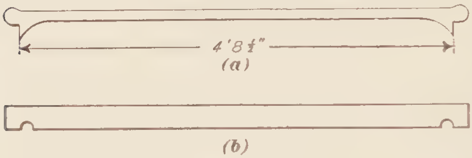


Fig. 44.

46. Rails With Conical Tread.—The treads of wheels are conical; that is, the diameter of tread next to the flange is larger than its diameter at the outside edge. This is done to allow the car to center itself on the track when the two wheels on the same axle are of different sizes. The device probably performs its function when there is no greater difference in the wheels than is found on two wheels of the same make just as they come from the foundry; this difference is, as a rule, not more than ⅜ inch in the circumference. But the beveled tread cannot be expected to amount to very much as an equalizer where the difference in diameter of the two wheels is ⅜ or ½ inch. Such a state of

affairs should not be allowed to exist, on account of the slippage it causes and for other reasons; but, unfortunately, in some cases it does exist. The general rule has been to make the top of the rail level, with the result that until there is a certain amount of wear in either the rail head or

FIG. 45.

FIG. 46.

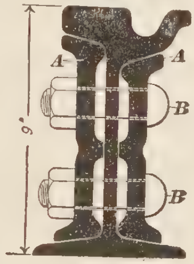


FIG. 47.

the wheel tread, the traction surface between the two is a straight line. In conformity with the observed fact that the side of the rail head next to the gauge line always wears down first, to meet the bevel of the wheel, the very sensible idea is now being practiced of making the top of the

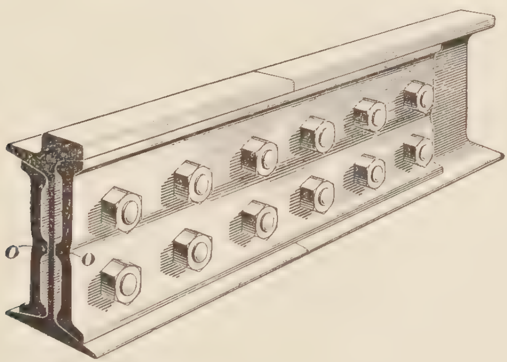


FIG. 48.

rail head also beveled to conform to the bevel on the wheel tread; the result is that the rail and wheel are a fit to begin with and do not have to wear down to that condition. This construction is said to effect a saving of about $33\frac{1}{3}$ per cent. in the life of the wheel and rail. Fig. 45 shows a girder rail

with a straight top; Fig. 46 shows one with a bevel top. Fig. 47 shows a section through a complete girder-rail joint. *A*, *A* are the **splice bars,** or **fish-plates,** so designed that they stiffen the joint. They are held up to the rail by **track bolts** *B*, *B*, which pass through the web of the rail. Fig. 48 shows a completed joint. Note the cross-section of the fish-plate; the rib at *O*, *O*, when the track bolts are screwed home, gives somewhat the effect of a lock washer and at the same time insures a definite contact surface between the plate and the rail. There are a great many patented devices in use for stiffening the joint and giving it solidity, and all of them have some merit; but the device that seems to be gaining the most favor with railway men is the cast-welded joint, which has already been described.

47. Guard Rails, Curves, and Special Work.—All roads have a greater or less number of crossings, curves, branch-offs, cross-overs, etc., and since these are different from straight track, in that they involve special care and precautions in their installation, they are all included under the general name of **special work.** Important special work is made up complete at the steel works and is shipped ready to install. When the work is in several pieces, ends that go together have the same mark, so that the trackman can make no mistake in his hurried efforts to complete the job without interfering with regular traffic. As the work of making up special work must be carried out with great precision (a difference of $\frac{1}{4}$ inch in the angle at which one arm of a frog or crossing sticks out may cause no end of trouble), it is carried out step by step, as follows: The site of the proposed work is first measured up carefully and a drawing of the survey made. This drawing is then carefully checked up and is used as a means to lay the work out in actual size with chalk on a hard, smooth, maple floor, known as the laying-out floor; if the job checks up all right, the floor lines and angles are used as a guide for making wooden templets to be used by the patternmaker and the rail bender. When the separate parts of the job are complete, it is set up in the

laying-out yard, where any slight errors or inaccuracies due to uneven shrinkage in the cast parts of the job or to want of care in the bending are detected.

In the switch, frog, and crossing part of special work, the greatest wear takes place at the points and breaks. On this account, several schemes have been adopted for not only increasing the hardness of the metal at these places, but for

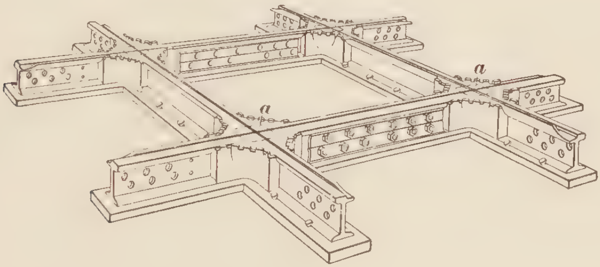


FIG. 49.

making the support stronger, so that the effect of the pounding will be less. There are many different styles of this intersection work. Fig. 49 shows one make of crossing, and the other makes are much the same in general appearance. Hardened centers *a* of manganese steel or other hard kind of steel are used at the points to prevent wear and hammering-out.

48. Curves.—Curves are of two kinds, **simple** and **compound,** or **transition,** curves. A simple curve is one that is described with but one radius throughout its length. A compound curve is one so constructed that the radii becomes shorter as the middle point of the curve is approached from either end. A compound curve is easier riding than a simple curve. Street-railway curves are always designated by the radius at the center. Long curves of light rail are sprung in, as a rule, that is, the rail is pried over with a bar and spiked into position, the paving being relied on to keep the track in place. The main objection to "springing in" a curve is, that if done on a curve of too

short a radius or with heavy rail, the job in course of time will give trouble at the joints; the ends of the rails straighten out and make an angle at the joint. This means that the car trucks in rounding such a curve will change direction in jumps, instead of gradually, and impart to the car a disagreeable, jerky motion not to be found on a curve that is smooth and regular. On curves of heavy rail and moderate radius, a portable rail bender should be used, while shorter curves should be bent to a templet with a power bender.

49. A very important point about laying out a single-track curve is to be certain that a car will go around it freely without either end overhanging the corner of the sidewalk or striking any obstruction. On double-track curves is also introduced the feature of two cars being able to pass each other without danger. It is not absolutely essential that the curves be such that two cars can pass each other on them, and in many existing cases it cannot be done. Very often, however, it involves but a small additional cost to so construct the curves that the cars can pass, and it is in the long run the best thing to do. Whether or not a curve will allow cars to pass on it depends on the following: the length of the car; the width of the car; the amount that the ends overhang the wheel base; the distance between the track centers; the curvature; the elevation of the outside rail; the length of wheel base; and, on double-truck cars, the distance between trucks. Also, the matter of fenders should be taken into account, as a fender increases the effective length of the car. As the trucks on a double-truck car are relatively nearer the ends of the car, the overhang in the center must be considered. The best plan is to lay out on paper and to scale a plan of the proposed curve; then, by means of a pasteboard dummy that scales the dimensions of the outside lines of the car, the actual clearance at all points can be readily determined. The positions of the car wheels must be indicated by holes through which the track can be seen, or transparent paper must be used, so that the dummy can be made to take the right path around

the curve. Another point to be looked after in cutting out a dummy to try on paper is to see that the widest part of the car is represented. To insure some degree of safety to the heads and arms of passengers, the clearance on both sides of the car should be at least 12 inches, if they are to pass each other on curves. Special attention must be paid to this feature where the center-pole method of line construction is used. There are many roads on which the curve clearance is not over 2 or 3 inches, but in most of such cases there is a rule against passing on curves.

50. Transition, or Compound, Curves.—These curves are formed by combining curves of different radii, so that the entrance of the car into the curve shall be gradual and a sudden shock avoided. The theoretically correct method

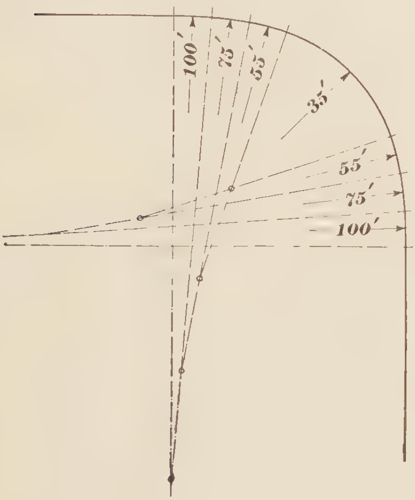


FIG. 50.

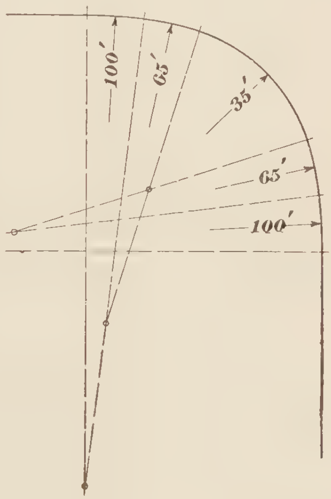


FIG. 51.

of laying out a curve would be to make a true spiral connection between the end of the straight track (called the tangent) and the center of the curve, but this would be practically impossible. Some engineers advocate a near approach to such practice by starting with a radius of some 600 feet or more and changing the radius every 2 feet,

as measured along the track, when laying out the approach to a main curve of, perhaps, 35 feet radius. Such frequent change of radius would be very difficult for a trackman to accomplish, and would probably not be done; it is sufficient to change the radius at distances equal to the length of the wheel base, an initial radius of 100 feet being large enough for street-railway work. It is not easy to construct switches for a greater radius, and since they are used on probably 50 per cent. of the curves, this must be taken into consideration. In Fig. 50 the transition curves for a main radius of 35 feet are shown. Each chord, or length of curve having the same radius, is about equal to the wheel base of the cars, and there are three curves completing the transition, having radii, respectively, of 100, 75, and 55 feet. Fig. 51 shows a curve with only two transition curves. In both cases the initial curve has a radius of 100 feet, and the remaining curves should be divided equally between that radius and the radius of the main curve. Thus, for the curve forming the junction of the 100-foot and 35-foot curves, a radius of 65 feet, about midway between these numbers, is taken.

51. Designation of Special Work.—Fig. 52 (*a*) shows a *plain curve*, in the sense that it is not complicated by any branch-offs, turnouts, or other special features. Such a curve can be simple or compound, single or double, right-hand or left-hand. Fig. 52 (*b*) shows a *left-hand branch-off* and Fig. 52 (*c*) a *right-hand branch-off;* these are used where a branch road leaves the main line. Facing the point of departure of the branch from the main line, a right-hand branch-off turns to the right and a left-hand branch-off to the left. Fig. 52 (*d*) is known as a *connecting curve and crossing*. In the figure, the curve is a right-hand branch-off to the horizontal straight track and a left-hand branch-off to the vertical one. Fig. 52 (*e*) is what is known as a *plain* **Y**. Fig. 52 (*f*) is a *three-part* **Y** and Fig. 52 (*g*) a *through* **Y**. The three-part **Y** can be used instead of a loop to turn single-end cars at the end of the line. Fig. 52 (*h*)

is known as a *reverse curve*, and must often be used where a cross street is broken at the main street. Fig. 52 (k) is a *right-hand* and Fig. 52 (l) a *left-hand cross-over*, used to

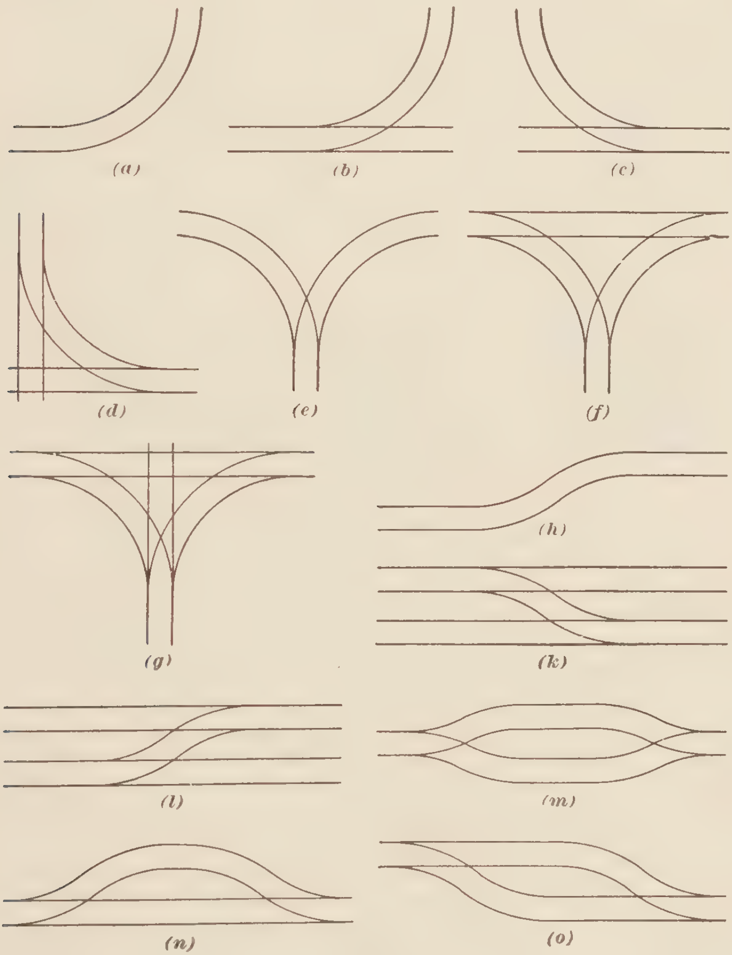


FIG. 52.

cross over from one track to the other. These are very convenient devices to place here and there in a main line to turn cars back, either when they are crippled or to get them

on their time after a long delay. When it is practicable, a cross-over should be put in so that its switch points will lay in the direction of travel on the two tracks. Fig. 52 (m) shows a *diamond turnout;* Fig. 52 (n), an ordinary *siding*, and Fig. 52 (o) what is called a *thrown-over turnout*, seen very often in temporary work, where it is of the nature of a temporary cross-over to avoid a gang of workmen.

52. Guard Rails.—Guard rails are rails provided with a protecting flange to prevent a car from climbing the rail on a curve. Guard rails can be solid or made up. Girder guard rails are, as a rule, solid; T rails are made up. Fig. 53 shows a section of a girder guard rail and Fig. 54 shows a section of T rail provided with a guard. The T rail need only be provided with a regular guard where it is used in a paved street. In country work, the steam-road practice of laying a second line of T rail next to the inside-track rail is adopted. This practice is also adopted, as a rule, on bridges, where the guard rail is, however, laid beside both track rails. The best authorities are inclined to the belief that a guard rail on the inside, or short rail, of a curve affords ample protection, but it is common to see a guard on both the inside and outside rails of short curves. At any rate, it is not safe to rely on the flange of the outer wheel alone to keep the car on the track, for car wheels in street-railway service, on account of the heavy weight attached to the axle and also on account of the nature of the special work that they have to jolt over at times, are addicted to the trouble of broken or chipped flanges. A wheel with such a defect in the flange is almost certain to climb the rail if that wheel is on the front end of the car as a leader. As in the case of ordinary grooved rail, a great deal of judgment must be used to select a groove that is adapted to the flanges of the wheels used.

FIG. 53.

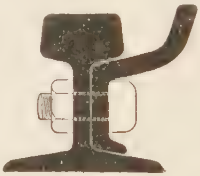


FIG. 54.

EXAMPLES OF STREET-RAILWAY TRACK CONSTRUCTION.

53. Fig. 55 shows a cross-section of a very substantial roadbed used in the State of New York. The figure shows a single track only, although the road is double track. A trench 23 inches deep is opened up 18 feet wide. This is well rolled and filled to a depth of 8 inches with 2-inch broken stone, soft spots in the rolled surface being dug out and also filled with the stone or other solid material. The stone is rolled until it is firm at a depth of 8 inches. On this ballast are laid the ties, 6 in. × 7 in. × 7 ft. 6 in., a little less than 2 feet between centers, except at the joints,

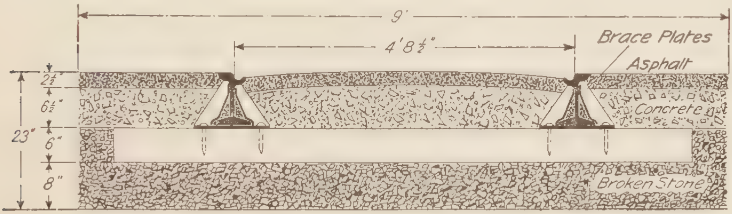


FIG. 55.

which are supported by three ties about 15 inches between centers; 60-foot rails are then laid on the ties, ends butted and joints staggered. Before jointing, the ends of the rails and the joint plates are well cleaned to take the bonds. The rails are then coupled, the plates bolted tight, brace plates installed every 3 or 4 feet, ties lined up and spiked to the rail. The track is then lined and surfaced and the space between the ties filled with broken stone, well tamped to the top of the tie. The rail is then finally lined, the joints secured, and the broken stone or concrete brought up to the paving.

54. Fig. 56 is an example of roadbed construction on a weak subsoil, and Fig. 57 shows a very novel method of paving to a **T** rail. In the roadbed construction in Fig. 56, a trench 36 inches deep and the width of the tracks is dug; the trench, as shown by the figure, is filled to a depth of 29 inches with successive layers of 12-inch hard earth and

rock well beaten down; 10-inch earth, pebbles, clay, sand, and rocks, well tamped; 7-inch new concrete; and 6 in. × 8 in. × 8 ft. hard pine ties, previously boiled in asphalt, are laid on the concrete to take 80-pound **T** rails. At joints the ties are supported on steel plates bolted to the concrete. The track is 3 feet 6 inches gauge and 12 feet between the centers. The paving is flush with the head of the rail on the outside.

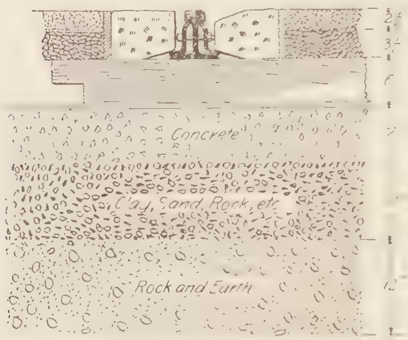


FIG. 56.

On the inside of the rail it is brought up, except at joints, to the lip of an **L** plate supported, as shown in Fig. 57, by the foot of the track rail and tied by a bolt that passes through it, the web of the rail, and the body of a **Y** filler, which acts as a groove for carriage wheels. At the joints where the **L** rail is discontinued, the groove is formed by stone blocks set in a steel frame. This method of construction, while somewhat bold, has given great satisfaction.

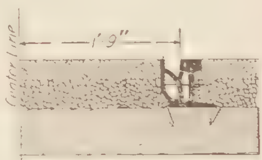


FIG. 57.

55. Fig. 58 shows a track construction where the rails are supported on concrete stringers *A*. The rails are connected together by steel crossties. This figure shows the method of paving brick up to a **T** rail, and Fig. 59 shows the method of bringing up the asphalt. The rail is a 60-pound **T**, 6 inches high, in 60-foot lengths. On straight track, it is laid on 24-pound steel ties, 3 feet between centers,

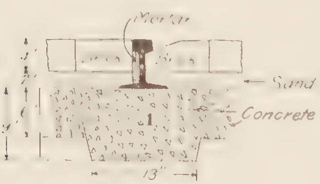


FIG. 58.

and on curves and special work, on 6 in. × 8 in. × 6 ft. 6 in. oak ties. All joints are broken or staggered and are carried on steel plates. In the construction shown in Fig. 59, the concrete comes above the foot of the rail; in order to get it well tamped under the rail and to avoid troubles incident to shrinkage on setting, the concrete was mixed with as little water as possible. The construction work, in brief, was as follows: After the old track was removed and the street dug out and rolled to grade, the new work was put in place, assembled, surfaced, lined, and gauged while temporarily supported on wooden blocks. The trenches for the concrete beams or stringers were then dug and the wooden formers placed in position. The 6-inch paving concrete was next laid, allowed to set for a day, and the formers removed to make way for the stringer, which was then installed. The concrete in the stringer was allowed to set for a week before a car was permitted to go over it. As the work was done in extremely hot weather and as the variation in length of the exposed rail was about 10 inches per 1,000 feet between night and day, the disastrous effects of this great expansion and contraction had to be prevented. This was done as follows: In the brick construction, as fast as the paving concrete was laid, the sand to be used as a paving bed was heaped over the rail and wet down; this was supplemented by turning V-shaped wooden troughs upside down over the whole.

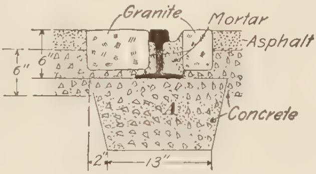


FIG. 59.

56. Fig. 60 shows a section of track construction in Detroit. It employs the best features of the two systems that formerly existed there and includes the concrete beam and the steel cross-tie (3-inch angle bars), used more as a tie-rod for keeping the rails to gauge than as a solid resting place for the rails. The concrete-beam work ordinarily goes to a depth of only 6 inches, but in soft spots it goes to

a depth of 2 feet, if necessary. The concrete used in the beam is composed of 1 part Portland cement, 4 parts Louisville cement, 8 parts sand, and 16 parts broken stone, laid to a depth of 6 inches in a trench and brought up 1½ inches above the bottom of the ties.

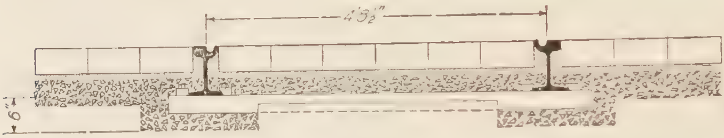


FIG. 60.

57. Fig. 61 is a section through a roadbed construction used in Chicago. One of the standard constructions is as follows: The street is excavated to grade to receive a layer of broken stone rolled to a depth of 6 inches; on this stone, 2 feet between centers, are laid the white oak ties 5 in. × 8 in. × 7 ft.; the rails, 85-pound girder section, are spiked to the ties and the space between ties is filled with broken stone or slag, which is well tamped to surface, and the rail lined. After the track is lined and surfaced, the stone is brought above the surface of the ties, where is placed a 1-inch

FIG. 61.

layer of sand on which the paving blocks rest. The depth of the roadbed has lately been increased from 6 to 8 inches; this, together with the fact that 60-foot rails and cast-welded joints have been adopted, will go a long way towards lessening the trouble from poor joints. There are over 100,000 of these joints on a single system, and all the roads have their own cast-welding outfits. So much faith is there in the conductivity of the cast-welded joint that in some instances the use of bond wires has been discarded. The

wisdom of this practice, however, is very doubtful. Unless the several lines of rail are well cross-bonded, the development of a single bad joint might materially affect the voltage at some remote part of the system.

58. Construction in Soft Subsoil.—Fig. 62 shows a style of track construction used in New Orleans. This city is very little above sea level, and most of the year the river is above the city. These facts, together with the fact that the subsoil is thoroughly permeated with holes made by the crawfish, make the city a floating land in the sense that wherever a hole is dug it immediately fills with water. It is not hard to conceive, then, how a roadbed constructed along the usual lines would soon give trouble. Several of the long lines in the city are built on neutral ground between two driveways, so that they are not subjected to the wear and tear of wagon traffic. This location of the

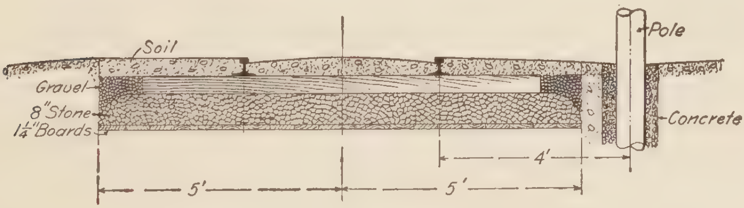


FIG. 62.

tracks admits of the use of a **T** rail. Fig. 62 shows a section of the **T**-rail construction. The first step is to dig two trenches, one for each track, about 2 feet deep and 10 feet wide. The space between tracks and between the tracks and the roadways is all grass-grown, and as there is no traffic on it, no roadbed is needed. On the bottoms of the leveled trenches are laid lengthways $1\frac{1}{4}$-inch yellow-pine boards. This acts as the foundation for a layer of $1\frac{1}{2}$-inch broken stone, on which the 6 in. × 8 in. × 8 ft. creosoted yellow-pine ties rest, 2 feet between centers. The space between the ties is filled partly with broken stone and partly with gravel that goes to the top of the ties. On top of the

gravel is put a layer of soil in which grass is sown, so that a few months after the work is done the whole neutral ground is grass-grown—a feature that almost entirely does away with the clouds of dust ordinarily raised by a car in course of rapid transit. The plank construction on the bottom of the roadbed prevents the tendency of the track to sink into the soil and cause undulations in the surface line of the rail. The use of the T rail does not introduce complications at crossings, some of which are asphalt and others stone, because all wagon traffic being across the rail, no provision need be made for carriage wheels. At asphalt crossings the paving is brought right up to the head of the rail on both sides and the car-wheel flanges are allowed to cut their own flange ways. At stone-paved crossings the stone is flush with the rail head on the outside and on the inside a narrow space is left as a flange way. The rail used in this particular construction is 5¾ inches high, weighs 100 pounds to the yard, and is in 60-foot lengths. The joints are broken and are bonded with a No. 0000 B. & S. concealed bond.

59. Construction for Conduit Road.—There are no overhead wires allowed in the city of New York, so that all track work must be made to conform to the use of a slot to pass a cable grip or a trolley plow. The Third Avenue

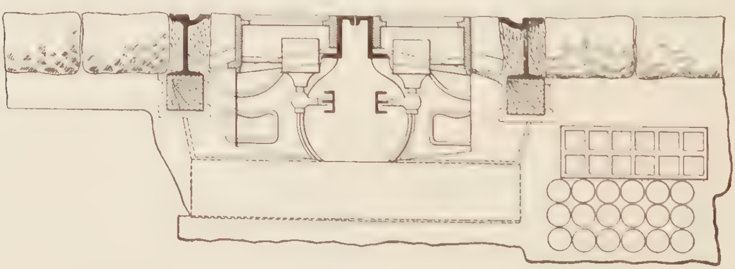


FIG. 63.

Railway affords an example of recent track work for a conduit road. The first step towards installing a conduit is to dig a trench about 3 feet deep and the width of the roadbed. The trench is rolled to grade and a 4-inch layer of concrete

put on its bottom. Fig. 63 is a section through the construction in question. The 4-inch layer of concrete forms a surface on which to aline the ironwork, all of which is assembled before the main body of concrete is installed. The track rails and slot rails are supported on iron yokes spaced 3 feet apart and made up in three pieces, which is a new feature in such work. The three members are a steel **I** beam *A* and two cast-iron side pieces *B* (see *A* and *B*, Fig. 64) weighing about 125 pounds each. The yokes rest on the 4-inch concrete bottom, and the space between the yokes, the center of which space is the conduit proper, is filled with concrete that must be put in after the iron is in place,

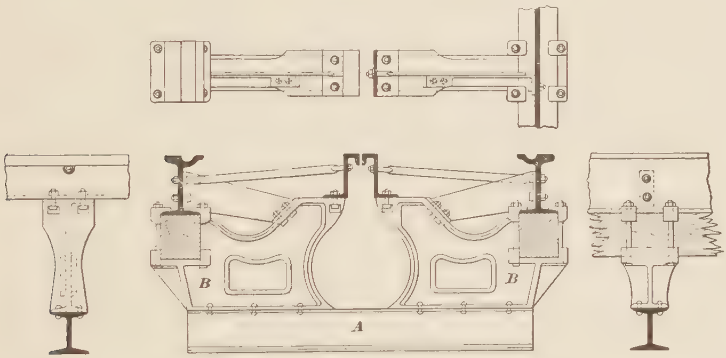


FIG. 64.

because the throat of the yoke dictates the general shape of the concrete part of the conduit. In order to shape the walls between the yokes, iron linings are used to support the concrete until it has set. These linings are made so that they can be freely drawn through the slot either way, and they are forced into position by means of a folding form operated by a lever. Fig. 64 gives a section through a plane that shows one of the yokes. The track rails are 9-inch grooved girders 107 pounds to the yard, in 60-foot lengths, laid on pine stringers. This stringer construction is a new feature in this class of work and is in accordance with the idea held by many engineers that a rigid support for the rails does not afford an easy riding track.

THIRD-RAIL CONSTRUCTION.

60. General Remarks.—The supply of current to cars has already been described in a general way in *Electric Railways*, Part 1. This method is coming largely into favor where the traffic is heavy. It has already been adopted on a number of elevated roads in New York, Brooklyn, Chicago, etc. It has also proved much superior to the overhead trolley for cross-country lines. It seems to be the only system adapted to the supply of heavy electric currents at normal voltages to meet the requirements of steam-road traffic conditions. In high-speed work, it is absolutely necessary to employ a rigid conductor that will not sag or sway under the influence of the moving contact. A good heavy steel rail seems to fulfil this condition to perfection. This rail, which gives the name to the system, is laid either between the two track rails or to one side and above one of them. The center-rail construction is safer in so far that it offers less opportunity for a person to step on it from the track rail, but this feature should not be relied on for safety. On the other hand, the side-rail construction is free from all liability to short-circuits due to a motor or brake rod or other part of the equipment coming loose in service and falling across the track rail and the third rail. The third rail is of much more assistance as a conductor than the ordinary trolley wire, because it has a large cross-section, and thus cuts down the amount of copper required for feed wires.

61. Examples of Third-Rail Construction.—The construction used on the Nantasket Beach road and described briefly in *Electric Railways*, Part 1, was one of the earliest third-rail systems installed in the United States. In this case, a third rail of special shape was used, but in the later roads it is nearly always of the ordinary T shape. In some cases these rails are insulated by supporting them on creosoted wooden blocks; in other cases they are supported on insulators made of "reconstructed granite," porcelain, or other insulating material. In Brooklyn, the third rail is

outside of and above the track rail; sometimes on one side of the track and sometimes on the other, according to the surroundings. Each motor car carries four contact shoes, one on each corner of the car, and two of these shoes are always in a position to be active. The third rail is made up of all kinds and weights of old **T** rails, with the result that the joints are in some cases very uneven and have given a great deal of trouble by knocking off the contact shoes. The rails are held together by fish-plates and are bonded similar to the track rails. At branches, turnouts, cross-overs, sidings, etc., where it is necessary to break the line of the third rail, end pieces called **nosings** are fastened between the ends of the third rails and act to guide the shoes on the rail again. These nosings, which are of cast iron, are wider than the rail itself. They are bent down considerably on the ends and are renewable. They are found to give better service than bending the rail itself down to form a nosing. Where the line of the rail is broken in this way, the circuit is made continuous by means of a copper connecting cable. The third-rail line is supported at close and regular intervals on strong insulators made of reconstructed granite. The contact, or collecting, shoes are fastened to that part of the truck that is deflected least, and hence varies least in height when the load on the car changes. The shoe beam must, therefore, be hung from a point that is not responsive to the action of the main-truck springs. On account of this comparatively rigid suspension of the shoe beam, with its contact shoes, it is absolutely essential that the surface line of the third rail be true and level and that the tops of the rails at joints be exactly flush; if they are not, as experience has proved, there will be no end of trouble from losing contact shoes. As a factor of safety, it is well to make the slotted links, by means of which the steel shoes are hung from the steel rack, of gray cast iron, so that in case the passage of the shoe along the rail becomes obstructed for any reason, the links will give away and the rack and beam will be spared.

62. Fig. 65 shows the style of contact shoe used on the Albany and Hudson third-rail road. It will be noticed

FIG. 65.

that it is very similar in general design to that described in *Electric Railways*, Part 1, as used on the Nantasket Beach road. Fig. 66 shows the style of support used for the third rail on the Albany and Hudson road. Every fifth tie is extended to one side so as to take the third-rail support, which consists of a wooden block *A*, to which is attached the malleable cast-iron top *B*. The third rail is held by keys under the ears *c*, *c*. This road uses an 80-pound **T** rail for the third-rail conductor.

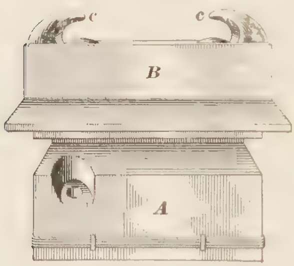


FIG. 66.

63. Snow and Ice on Third Rail.—Snow and ice often cause a great deal of annoyance in connection with the operation of third-rail roads. There are times when the third rail gets so thoroughly coated or glazed with a thin layer of ice that the trains have been unable to run at all. The ice is such a poor conductor that the current will not go through it as thin as it is, and yet it is so smooth and hard that no mechanical device outside of a milling machine will effectively remove it from the surface of the rail. Several devices have been tried for keeping the rail clear of ice; among the most effective may be mentioned a free use of oil to keep the ice from forming and a free use of brine to remove the ice if it is already there. Both of these schemes have been only partially successful, but have

done good work in the absence of better means. It has been the practice to apply the oil by means of an ordinary swab in the hands of men placed at intervals along the line; the salt water can be squirted on to the rail by means of a small rubber hose, leading from a tank placed on the rear end of a train or car especially adapted to do the work. The oil cannot be so applied, because the problem of getting the liquid, whatever it may be, on the rail and not in the street below has given a great deal of trouble.

64. Third-Rail Precautions.—The ordinary third rail cannot, of course, be used for surface roads in cities. Its use for city work is, therefore, confined to elevated roads. In densely populated parts, the third rail should be split up into a number of sections, and the feeders supplying these sections should be provided with switches, so that in case of fire, either on a car or in nearby buildings, the current may be cut off. In case of fire, the live third rail is very often a source of hindrance to the firemen in the performance of their duties, and in some cases is even a source of danger. When a fire, caused by some abnormal condition of the circuit, occurs on a motor car, the only way to break the current, if the feeder switch cannot be reached and the circuit-breaker is out of order, is to lift the contact shoes from the rail, and this is not an easy thing to do, unless there are special means provided for the purpose. Every motor car should be provided with a pair of wooden paddles with handles about 3 feet long. To cut off the current, it is only necessary to shove one of these paddles in between the third rail and each of the two active contact shoes.

ELECTRIC RAILWAYS.

(PART 4.)

CALCULATION OF FEEDERS.

1. In the transmission of current for electric railways, as in other cases of electric transmission, we are usually limited to a certain amount of loss or drop in the line. If the loss is large, we can use a comparatively high-resistance line with a corresponding small amount of copper. A large line drop, however, means a low voltage at the cars unless the voltage at the station is automatically increased as the load increases. Low line voltage makes it hard for the cars to maintain their schedule and always gives rise to trouble with the motors, to say nothing of the actual cost of the power wasted in the line. It does not pay, therefore, to allow the line loss to become excessive, and the feeders must be designed to keep the drop within the specified amount. The average percentage loss may vary greatly. It is seldom that the drop is less than 10 per cent. (50 volts), and in a great many cases it runs much higher than this.

2. The weight of the rail is fixed by traffic considerations, so that an approximate estimate of what the drop in the return circuit will be can be formed at the outset. The balance of the drop will then give that allowed for the feeders, and they should be designed to conform to this as nearly as possible. Feeders designed under this condition seldom fail to fulfil the requirements of the average drop.

For notice of copyright, see page immediately following the title page.

There is a great difference between the maximum and average loads in the stations, and the smaller the station, the greater the difference is liable to be. For this reason, the average drop and maximum drop may be widely different. Take a case where the road operates only two or three cars and the load fluctuates between zero and the maximum several times in perhaps a minute. Before the size can be assigned to the feeders, the average load that each feeder has to look after must be approximately known or ascertained. In doing this, it is very convenient to divide the line into sections, assign to each section the load that probably will be on it, and proportion the feeders accordingly. Incidental to this method, a certain maximum drop or average drop must be assigned to each of the feeders, so that the operation of the cars on all sections of the line will be practicable under all ordinary conditions.

3. Estimation of Load. — In assigning the probable loads to the several sections, some knowledge must be had of the number of cars that are to be run and of their headway or distribution. A knowledge of the weight of the car and its equipment is also necessary in order to determine the current that the car will take under average conditions. As far as the *relative* sizes of the feeders and their points of feeding are concerned, any convenient unit of current per car can be selected, but in order to determine the *actual* size of the feeder in order to keep the drop within the specified amount, its actual load in amperes must be at least approximately known.

4. Rules for obtaining the current required under different conditions have already been given in *Electric Railways*, Part 2. The current, if supplied at a fixed voltage, is almost, if not quite, proportional to the speed of the car. Not only the variable speed at which the cars will run, but other things will tend to make the current required per ton a variable quantity, so that unless the road is already in operation and the average current consumption per car is known or can be found out, it will be necessary to know

the style of car, motors, etc., and the conditions under which they are to be run, or to take this value from the experience of others. Let us assume a 24-foot car body equipped with 37-horsepower motors and call the average current per car throughout the day 20 amperes. This may strike one as a very low value when compared to the current called for when the two motors run at their rated output, but it must be borne in mind that a great deal of the time the car takes no current at all, for it may be coasting or standing still with the power off. The value of the average current per car is obtained by taking current readings on the car at regular intervals throughout several characteristic trips. The closer these readings are taken together, the more accurate will be the result. These current values are all added together and divided by the number of readings, and this gives the average of the current during the time covered by the test. This test should be made at a number of different hours during the day and the average value of all these average results taken. This final average is the load to be assigned to each of the several cars; this load multiplied by the number of cars to be run gives the average load of the whole road, or the load that the feeders will be called on to handle. The car referred to above is of medium size. Large double-truck cars would take a much larger current, the average probably being from 50 to 75 amperes, depending on the grades, etc.

5. Example of Feeder Calculation.—On account of its mechanical strength, low cost of maintenance, and good conductivity, the trolley wire in the following calculations will be assumed to be No. 00 hard-drawn copper having a resistance of about .08 ohm per 1,000 feet. This value covers the average conditions of temperature.

Fig. 1 shows the layout of a road that we will assume to be 5 miles long. The system is fed from a power station at one end of the line and operates ten cars using on an average 20 amperes of current per car, making a total of 200 amperes. It is prescribed that the total load

concentrated at the end of the line shall not produce a drop of over 100 volts. If the trolley wire is No. 00, what must be the size of the feeder *B A*?

The road is single track, so that there is available the conductivity of two lines of rails in the return circuit. These rails will be 5 miles long, and at .0111 ohm per 1,000 feet, including bonds, will measure .0586 ohm per mile; 5 miles of track will, therefore, measure $.0586 \times 5 = .293$ ohm,

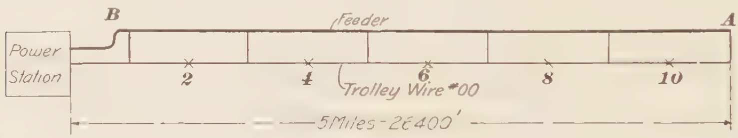


FIG. 1.

which resistance, carrying a current of 200 amperes, will cause a drop of $200 \times .293 = 58.6$ volts, leaving a drop of $100 - 58.6 = 41.4$ volts to take place in the trolley wire and feeder. If we assume that the conductivity of the copper in the trolley wire is the same as that in the feed wire, we may use the formula

$$\text{Circular mils} = \frac{10.8 \times L \times C}{e}, \qquad (1.)$$

where L = length of wire in feet through which the current C is delivered;
C = current supplied;
e = drop in volts.

The number of circular mils given by this formula will be the combined cross-section of the trolley and feeder, because these two wires are tied together in parallel throughout their length. In this case, $L = 26,400$ feet, $C = 200$ amperes, $e = 41.4$ volts; hence,

$$\text{Circular mils} = \frac{10.8 \times 26,400 \times 200}{41.4} = 1,377,400, \text{ nearly.}$$

The trolley wire is No. 00 and has an area of cross-section of 133,079 circular mils, as will be seen by referring

to the wire table in *Electric Transmission*, Part 1. Deducting this from the total cross-section called for, leaves 1,377,400 − 133,079 = 1,244,321. This will be a very large feeder, and 5 miles of it would be very expensive.

6. Another Solution of the Same Problem.—In the above we assumed that the trolley wire was of practically the same quality of copper as the feeder. This makes the solution simple and accurate enough for all practical purposes, because the trolley wire is small compared with the feeder. We will assume that the hard-drawn trolley wire has a resistance of .08 ohm per 1,000 feet, which is somewhat higher than the resistance of a soft-copper wire of the same size, and work out the example by a different method in order to compare results.

The drop in the overhead system is limited to 41.4 volts, and as the current is 200 amperes, the resistance must be $R = \frac{41.4}{200} = .207$ ohm. The total resistance of the trolley wire itself is $.08 \times \frac{26400}{1000} = 2.112$ ohms. The feeder must then be of such a size that when it is connected in parallel with a resistance of 2.112 ohms, it will bring the combined resistance of the two down to .207 ohm. If R is the combined resistance of the two resistances R_1 and R_2 connected in parallel, then

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}.$$

Since we know the values of R and R_1, it is necessary to solve the above equation for R_2. The above equation may be transposed as follows:

$$\frac{1}{R} - \frac{1}{R_1} = \frac{1}{R_2}.$$

This equation, by reducing the left-hand side to a common denominator and then inverting the fractions, may be transformed so as to give

$$R_2 = \frac{R \times R_1}{R_1 - R}.$$

Since $R = .207$ and $R_1 = 2.112$, we get, by substituting these values in the last expression,

$$R_2 = \frac{.207 \times 2.112}{2.112 - .207} = .229.$$

Five miles of the feeder must then measure only .229 ohm. We have the general formula

$$R = \frac{10.8 \times L}{\text{cir. mils}},$$

where R = resistance of a copper wire;
L = length of the wire in feet;
cir. mils = area of cross-section of the wire in circular mils.

Or, we may write

$$\text{Circular mils} = \frac{10.8 \times L}{R}. \qquad \textbf{(2.)}$$

and in this case

$$\text{Circular mils} = \frac{10.8 \times 26{,}400}{.229} = 1{,}245{,}065.$$

This, it will be noticed, is a slightly larger cross-section than was called for by the previous method, but the difference is not of practical importance for a cable of such large size. Formula **1** is accurate enough for general use and gives the simplest means of getting at the required feeder cross-section.

7. The student should note particularly that in working the above example a fair value for the track resistance was assumed and the drop in the track circuit then estimated. This drop was subtracted from the total drop, thus giving the value e used in formula **1.** Formula **1** does not, therefore, in itself take the track resistance into account.

In the last example it was found that a very large feeder was needed to meet the requirements. Of course, these requirements were severe, because the drop was not to exceed 100 volts when all the cars were bunched at the end of the line. In most cases the cars would be moving along over different sections of the line, and this would lessen the drop

on the system, because some of the cars would be comparatively near the station. At the same time, conditions arise where the cars may all be bunched at the end. In this particular case, therefore, it would be well to raise the voltage to 600 at full load at the station, either by using a very heavily overcompounded generator or by using a booster.

8. Example With Power House in Middle of Line.—If the power house were situated at the middle of the line, the amount of copper required would be very much less, as will be easily seen by referring to Fig. 2. The limiting condition is the same as before; that is, the drop from S to A or B must not exceed 100 volts when all the cars are concentrated at either A or B. If the cars are bunched at either A or B, 200 amperes must be transmitted through $2\frac{1}{2}$ miles

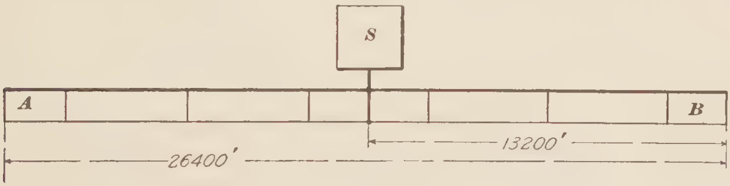


FIG. 2.

of track and feeder. Taking the track resistance as .0111 ohm per 1,000 feet, the resistance of $2\frac{1}{2}$ miles of track will be $\frac{13200}{1000} \times .0111 = .1465$ ohm. The drop in the track part of the circuit will, therefore, be $.1465 \times 200 = 29.3$ volts. This leaves a drop of $100 - 29.3 = 70.7$ volts to take place in the feeder and trolley wire. The length of feeder and trolley wire is $2\frac{1}{2}$ miles; hence, by applying formula **1**, we have the combined cross-section of the two,

$$\text{Circular mils} = \frac{10.8 \times 13{,}200 \times 200}{70.7} = 403{,}281.$$

The trolley wire supplies 133,079 circular mils of this cross-section; hence, the cross-section of feeder required is $403{,}281 - 133{,}079 = 270{,}202$. It is easily seen that placing the power house near the middle of the line results in a very large reduction in the amount of copper required.

9. It may be of interest, in passing, to see what the effect would be in the above two cases if the feeder were done away with altogether and the trolley wire increased in size to No. 0000. In the first case, 200 amperes would be transmitted over 5 miles of trolley wire. No. 0000 trolley wire has a resistance of about .05 ohm per 1,000 feet. Five miles of No. 0000 wire would, therefore, measure 1.32 ohms. A current of 200 amperes through this resistance would cause a drop of $200 \times 1.32 = 264$ volts, which, even if the power-house voltage were maintained at 600, would leave only 336 volts for the operation of the cars, to say nothing of the drop in the track part of the circuit, and this would not be sufficient for satisfactory operation.

In the second case, with the power house at the middle of the line, the drop in the trolley wire would be only one-half as great, because the wire would be only one-half as long, but even then the drop would amount to 132 volts in the trolley wire or $132 + 29.3 = 161.3$ volts altogether. If the station voltage were the standard 500 volts, the pressure at the cars would then be $500 - 161.3 = 338.7$ volts, which would not be sufficient to run the cars on schedule time. If, however, the power-house voltage could be raised to 600 at full load, a pressure of 438.7 volts would be obtained at the cars. This voltage, while not as economical from the car-operation point of view as it should be, is entirely practicable, as there are very few roads where the voltage under conditions of concentrated end load is as high as 475 volts.

10. Effect of Distributed Load.—So far we have worked out these feeder problems on the assumption that the load was bunched at one end. This is a condition that sometimes arises in practice, but it can hardly be looked on as the ordinary operating condition. In most cases we have a number of cars spaced at fairly regular intervals along the line, each car moving at an approximately uniform rate. The result of this is that current is taken off at a number of points that are continually shifting along the line. The load is practically uniformly distributed and there is a

gradual falling off in current from the station to the end of the line. For example, suppose $A B$, Fig. 3, represents a stretch of line that supplies six uniformly spaced cars moving at a uniform speed and taking 20 amperes per car. On account of the uniform movement and even spacing, the current will decrease gradually from 120 amperes at the station to zero at the end B. We may represent the falling off in the current by the line $C B$. The drop between A and B will, therefore, be found by multiplying the average current in $A B$ by the resistance. The average current is evidently one-half the station current, or 60 amperes; hence, if the resistance of $A B$ were, say, $\frac{1}{2}$ ohm, the drop between A and B would be 30 volts. If the whole load were

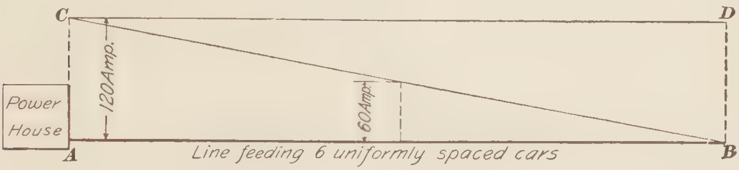


FIG. 3.

bunched at B, the current would be 120 amperes throughout the whole length, as represented by the line $C D$, and the average current throughout the length would be the same as the current at the station; hence, the drop would be $120 \times \frac{1}{2} = 60$ volts. From the above, it may be stated that *for a given line wire and a given amount of current transmitted, the drop with a uniformly distributed load is one-half that with a concentrated end load.* In other words, if we are making calculations relating to a distributed load and consider the whole length of line in our calculations, we must take the current as one-half the actual current supplied to all the cars, because the current falls off as previously described from the station, or feeding point, to the end of the line.

Another and perhaps a better way of considering a distributed load is to look on it as if the whole load were concentrated at the middle of the line and work out the problem as if the whole current were transmitted over half the line.

11. Example of Calculations for Distributed Load. Taking the road shown in Fig. 1, find what size of feeder will be required when the load is distributed and also when the drop to the end of the line is limited to, say, 50 volts. Here 50 volts has been taken as the allowable drop, as this is a common value aimed at in practice.

There are ten cars, each taking 20 amperes and uniformly spaced; the whole load of 200 amperes may be considered as being concentrated at the middle of the line, or it may be considered that an average current of 100 amperes is transmitted over the whole line. In order to be definite, we will choose the former and simply work the problem as if 200 amperes had to be transmitted through $2\frac{1}{2}$ miles of feeder and $2\frac{1}{2}$ miles of track with a drop of 50 volts. The track resistance was found to be .0586 ohm per mile, so that the resistance of $2\frac{1}{2}$ miles of track will be $.0586 \times 2.5 = .1465$, and the drop in the track $= .1465 \times 200 = 29.3$ volts. This leaves $50 - 29.3 = 20.7$ volts drop for the feeder and trolley. Then the combined cross-section of the feeder and trolley will be

$$\text{Circular mils} = \frac{10.8 \times 13{,}200 \times 200}{20.7} = 1{,}377{,}400.$$

It will be noticed that this combined cross-section is the same as that found necessary to supply an end load with a drop of 100 volts. In other words, with the same amount of line copper a uniformly distributed load will produce only one-half the drop that a bunched end load will cause, or if the drop is kept the same in both cases, the amount of copper required for the distributed load will be only one-half that called for by the concentrated load.

With the system shown in Fig. 1 and a combined cross-section of feeder and trolley of 1,377,400 circular mils, there will be a drop of 50 volts when the cars are uniformly distributed, and if for any reason it becomes necessary to bunch the cars all at one end, the drop will become 100 volts.

The method of working out the case shown in Fig. 2 will be the same as the above except that the current supplied

each side of the station will be only 100 amperes, because the load is uniformly distributed and one-half the cars will be on each side. Also, this 100 amperes will be considered as concentrated at the middle of the 13,200 feet. This will require much less copper than when the load is concentrated at either end. In the above, the student must not forget that although we have considered the load as bunched at the middle of the line, the feeder runs the whole length, as indicated in the figures.

12. Example of Calculations for a Loop Line.—Fig. 4 represents a so-called **loop line** that runs down one street and comes up at the next street parallel to it. It is a modified form of the **belt line** that is supposed to encircle the business part of the city, but it differs from a

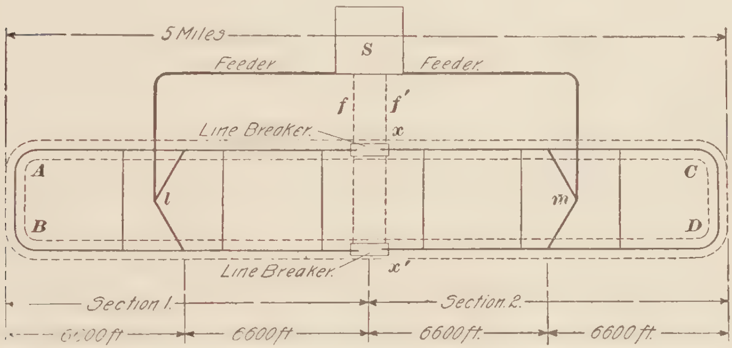


FIG. 4.

belt line in that, since the parallel lines are in neighboring parallel streets, the power house can, without great sacrifice of economy, be placed to one side of the area enclosed by the system, instead of being placed within this area.

In Fig. 4, *A C* is the street that the cars go up, *D B* the street on which they return. It must be noted that the area enclosed by the two tracks is very long in comparison to its width. The width between the streets is exaggerated in Fig. 4 in order to make the arrangement clearer. As a matter of fact, the loop would be very long and narrow.

The full line indicates the path of the trolley wire and the dotted lines that of the track. The two trolley wires are tied together at intervals so as to equalize the current between them; the rails are likewise tied together. The two heavy full lines running to the right and left of the power house indicate the two feeders that are tapped into both trolley wires at the middle of the sections. It is assumed that the trolley line is divided into two sections by the line breakers x, x' and that each feeder feeds in at the middle point of the sections. Since the two sections are independent and since each is supplied by its own feeder, we can calculate one of the feeders; the other will be the same, because the road is symmetrical. Since the cars are supposed to be uniformly distributed, the load on each section may be considered as being concentrated at the middle of that section, that is, in this case, where the feeders are attached. Taking each section by itself, it will be seen that this problem is similar in many ways to the last one worked out. Let us assume that the specifications require that the drop from the station to the feeding-in points l, m shall not exceed 50 volts when the cars are taking their average current and are uniformly distributed. A total of ten cars is operated and each car takes 20 amperes. The number of cars on each of the two sections will, therefore, be five and each feeder will have to supply 100 amperes. Since the trolley wire is fed from the middle point of each section and there are no feeders on the end of the section, there will always be more or less drop in the trolley wire itself. This drop will not, however, amount to much, as the distance from l to the end of the line or to the line breakers is short and there cannot be more than two cars in any one of these sections of trolley wire at the same time. The length of a section is $2\frac{1}{2}$ miles, or 13,200 feet; a half section is 6,600 feet, and a quarter section is 3,300 feet. For the present we will omit any consideration of the loss in the quarter section of double trolley wire and simply conform to the requirements of the limiting condition. The resistance through which the drop of 50 volts is to take place is that of four lines of

single rail well bonded together and the feed wire, both of which are $1\frac{1}{4}$ miles long. The current at which this drop will take place is 100 amperes. The resistance of $1\frac{1}{4}$ miles (6,600 feet) of double track is $6.6 \times .0056 = .037$ ohm, because the resistance of 1,000 feet of single 80-pound rail is .0223 ohm, so that the resistance of 1,000 ft. of single track, four rails in multiple, is $.0223 \div 4 = .0056$ ohm. A current of 100 amperes through a resistance of .037 ohm causes a drop of $100 \times .037 = 3.7$ volts. The total drop is limited to 50 volts, so that the drop in the feeders must be $50 - 3.7 = 46.3$ volts. The length of the feeder is 6,600 feet, so that we have

$$\text{Circular mils} = \frac{10.8 \times 6{,}600 \times 100}{46.3} = 154{,}000, \text{ nearly.}$$

A No. 000 B. & S. wire has a cross-section of 167,805 circular mils, so this size would probably be used, and $2\frac{1}{2}$ miles of this feeder would be needed to equip the road.

13. In the layout shown in Fig. 4, the trolley wires are not fed on the ends at all, and should the five cars on a section become bunched at one end there would be quite a drop in voltage in the trolley wire in addition to the drop in the feeder. Suppose all cars on section *2* to be bunched at *C*; a total current of 100 amperes will have to be supplied to these cars, and this current will have to flow through $1\frac{1}{4}$ miles of double trolley wire and back to the power house through the double track. The drop in the $1\frac{1}{4}$ mile of double track from *m* to *C* will be very small, so we will confine our attention to the drop in the trolley wire. Taking the resistance of the trolley wire as .08 ohm per 1,000 feet, $1\frac{1}{4}$ miles will have a resistance of $\frac{6600}{1000} \times .08 = .52$ ohm, approximately. There are, however, two trolley wires in multiple, so that the resistance from *m* to *C* will be .26 ohm; and, with a current of 100 amperes, the drop will be $100 \times .26 = 26$ volts. This drop, it must be remembered, will only occur under the extreme condition where the five cars on a section are all bunched at one end. Under normal

conditions, the drop in the trolley will not be more than one-quarter of this amount, or about 6.5 volts. This, together with the 50 volts loss allowed in the feeding system, will make the total average drop in the overhead system about 56.5 volts. If the voltage at the station is maintained at 500 volts, this will leave a pressure of 443.5 volts at the cars. However, most railway generators are overcompounded to give a rise of at least 10 per cent. in voltage from no load to full load, and with a machine of this kind the voltage at the cars will drop but little under 500.

Another way to allow for the trolley-wire loss is to make the feeder a little larger. In this case, increasing the size to No. 0000 will be sufficient, but unless there is a prospect of some future extension to the road or an increase in the number of cars, the best thing to do is to run the dynamos at a little higher voltage.

14. In Fig. 4, suppose we connect two feeders f, f', indicated by the dotted lines, one to each section, directly from the power house, and see what effect this will have on the voltage supplied to the cars. In practice, it will cost but little to do this, because these feeders will be very short. Consider one of the sections, say, section *1*. It is fed by the regular feeder previously calculated, and, in addition, the feeder f runs out directly from the power house and is tapped on the trolley wire at the line breaker. We will find what the drop would be under the most unfavorable conditions, that is, with the five cars on the section bunched at A. The whole current, 100 amperes, will have to return to the station through $2\frac{1}{2}$ miles of double track. In the overhead work there will be $1\frac{1}{4}$ miles of feed wire, and in multiple with this will be the two trolley wires extending back to the station, because the connection of the feeder f puts the trolley wires in multiple with the regular feeder. Up to the point l, therefore, we have the feeder and the two trolley wires in multiple to carry the current. Beyond l, to the end of the line, the current is carried by the two trolley wires alone.

The resistance of $2\frac{1}{2}$ miles of double track, assuming the resistance per 1,000 feet to be .0056 as before, will be .074 ohm. The resistance of $1\frac{1}{4}$ miles of two No. 00 trolley wires in multiple, if a single No. 00 hard-drawn copper wire measures .08 ohm per 1,000 feet, will be

$$\frac{.08}{1,000} \times 5,280 \times 1\tfrac{1}{4} \times \tfrac{1}{2} = .26 \text{ ohm.}$$

The resistance of $1\frac{1}{4}$ miles of No. 000 feeder wire is about .41 ohm, and this in parallel with the resistance of $1\frac{1}{4}$ miles of double trolley gives the resistance from the station to the point l as

$$\frac{.26 \times .41}{.26 + .41} = .16 \text{ ohm.}$$

The total resistance to the end of the line and return will then be $.074 + .26 + .16 = .494$ ohm. This will give a drop of 49.4 volts with a current of 100 amperes. It is thus seen that where the load is bunched at the far end, the addition of the feeders at the station does not improve the drop very much, because without the use of these feeders the drop would be about 56.5 volts. If, however, the load should become bunched at, say, l, the point where the feeder taps in, the track resistance will be .037, and the combined resistance of the feeder and trolley wires .16, making a total resistance of .197 ohm, and the drop will be only 19.7 volts as against 46.3 volts if the feeder alone were used. If the load were concentrated at the power-station end of the section, there would be little or no resistance in the circuit, save that of the tap wire and the ground-connection wire, so it is safe to say that the loss caused by a current of 100 amperes would not at this point be more than 5 volts. It is easily seen, then, that the effect of tapping the feeder in at the power-station end of the section and thereby getting the full benefit of the conductivity of the trolley wire is a good move, as it results in lowering the voltage loss due to resistance. The power-house taps, as well as the line feeder, must be provided with feeder switches, so that the current may be cut off any section desired.

15. Loop Line Supplied by Four Feeders.—In the last illustration it was shown that the introduction of taps, or short feeders running into the power house, had the effect of keeping up the voltage on all parts of the line to some extent, but that the effect was most pronounced on the part of the line comparatively near the power house. By adopting a little different method of feeding, we can keep the voltage more uniform at all points. In Fig. 4, it will be noticed that the feeding-in points are, as it were, lopsided. In other words, most of

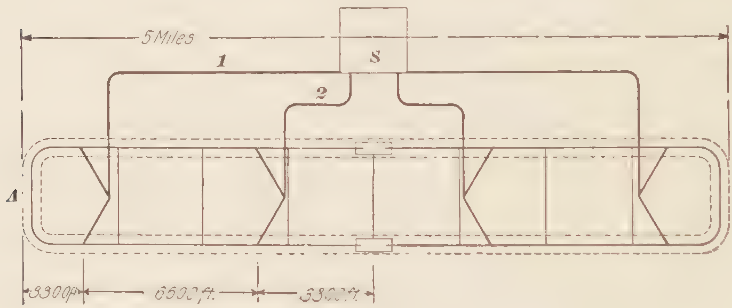


FIG. 5.

the feeding-in is done on the half of the section nearest the power house. We will, therefore, extend the feeders as shown in Fig. 5, and have the two points where the current is fed in 6,600 feet apart as before, but situated 3,300 feet, or $\frac{1}{4}$ section, from each end. The point where feeder *1* taps in will then be 9,900 feet from the station, and the point where feeder *2* taps in 3,300 feet from the station. The length of trolley wire projecting beyond the taps on both ends will be 3,300 feet.

As before, we will first see what the drop will be if the five cars are bunched at the end *A*. The current will have to come back through 13,200 feet of double track, which, as before calculated, has a resistance of .074 ohm. The flow of the current in the overhead work is somewhat more complex. In the first place, there are 3,300 feet of double trolley wire on the far end of the line; this will have a resistance of $.08 \times \frac{1}{2}$

$\times \frac{3300}{1000} = .13$ ohm. Next, the short feeder *2*, which we will suppose is the same size as *1*, is 3,300 feet long and is in series with 6,600 feet of double No. 00 trolley wire, and these two in series are in multiple with the long feeder *1*. No. 000 wire has a resistance of about .062 ohm per 1,000 feet. Feeder *1* is 9,900 feet long and has a resistance of $9.9 \times .062 = .614$ ohm. The resistance of the short feeder and double trolley wire combined is $3.3 \times .062 + \frac{6.6 \times .08}{2}$ $= .469$ ohm. This is in multiple with the feeder whose resistance is .614 ohm; hence, the combined resistance of the two will be

$$\frac{R_1 \times R_2}{R_1 + R_2} = \frac{.469 \times .614}{.469 + .614} = .26 \text{ ohm.}$$

The total resistance from the power house to the end of the line and back again will then be $.13 + .26 + .074 = .464$ ohm, and with a current of 100 amperes the drop will be 46.4 volts. This is better than was obtained with the first layout considered in connection with Fig. 4, where there was 50 volts drop to the feeding-in point and 26 volts more through the trolley wire.

16. Next, suppose the whole load to be located just at the long feeder tap. In this case the resistance is the same as before less the resistance of 3,300 feet of double trolley wire on the end and 3,300 feet of track. The resistance of 9,900 feet of rail return is $9.9 \times .0056 = .055$ ohm, nearly. The whole resistance will then be $.055 + .26 = .315$ ohm, and the drop will amount to $.315 \times 100 = 31.5$ volts.

17. If the whole load is located at a point midway between the two feeder taps, each feeder will have the same length of trolley wire in series with it and the two sets will be in multiple; also, there will be 6,600 feet of track in the circuit. The resistance of the long feeder and its 3,300 feet of double trolley will be $.614 + .13 = .744$ ohm. The resistance of the short feeder and its 3,300 feet of trolley wire will

be $.205 + .13 = .335$ ohm, and the resistance of the two sets in multiple will be $\frac{.335 \times .744}{.335 + .744} = .231$ ohm, nearly. The resistance of the track will be .037 ohm, thus giving a total resistance of $.231 + .037 = .268$ ohm for the whole circuit. This will cause a drop of 26.8 volts with the load concentrated between the taps.

18. If the load is just at the end of the short feeder tap, the circuit resistance will be distributed as follows: There will be 3,300 feet of rail return, and the long feeder will be in series with 6,600 feet of double trolley wire, and the two together will be in multiple with the short feeder. The working out of the drop in this case is left as an exercise for the student. It is in the neighborhood of 18 volts.

If the load is somewhere near the line breaker in front of the station, the loss is increased by 13 volts on account of the trolley wire between the tap and the line breaker. On the other hand, the drop will be decreased by nearly 2 volts, because there is no track included in the circuit with the load in front of the station. The net increase will therefore be about 11 volts.

The general effect of using the two feeders is to equalize the voltage on the system, thus enabling the cars to maintain a uniform speed.

The above simple examples have been selected to show the student how ordinary feeder calculations may be made. They do not, of course, cover the whole field of feeder design, but the principles and methods of calculating here given should enable one who is at all inclined to look into the subject to investigate and possibly improve the working conditions on a road of moderate size.

19. Comparison Between Track Resistance and Overhead Resistance.—As already stated, it is difficult to estimate the resistance of the track closely even if the weight of the rails is known, because the bond resistance is uncertain. Formerly, in making line calculations, it was assumed that the track circuit had no resistance, but, as previously

pointed out, this was far from the truth. Very often the resistance of the track circuit is taken as about $\frac{1}{4}$ that of the overhead circuit, but it is evident that no general relation between the two can be given, because, in the first place, the size of the rails may vary in different cases, and in the second place, the amount of copper put in the overhead line varies within wide limits, depending on the nature of the traffic and the amount of loss allowed.

The ordinary formula that we have been using for making feeder calculations,

$$\text{Circular mils} = \frac{10.8 \times L \times C}{e},$$

applies, as it stands, to the copper part of the circuit only, and the length L refers to the length of the copper part of the circuit through which the current C flows. If we know the relative amount of resistance in the track as compared with that in the line, we can modify this formula so as to take account of the resistance of the rail return. A formula of this kind is very convenient for making approximate calculations. According to Dr. Louis Bell, a constant of 14.4 instead of 10.8 will allow approximately for the resistance of the track return, thus giving the formula

$$\text{Circular mils} = \frac{14.4 \times L \times C}{e}. \qquad \textbf{(3.)}$$

This means that under average conditions of load and track-return resistance *the cross-section in circular mils of a feeder necessary to deliver a current C with a drop e is equal to 14.4 times the length of the feeder in feet times the current divided by the volts drop.*

It must not be forgotten that this formula is not exact in all cases; it merely represents average conditions. The constant appearing in the formula is found to lie between 14 and 15 on the great majority of roads as ordinarily built.

20. In order to further illustrate feeder calculations, we will work out the case of a small road and at the same time make use of formula **3** in order to illustrate its application.

EXAMPLE.—Fig. 6 shows the layout of a single-track road operating nine cars, which are spaced fairly evenly along the line. The road is divided into two sections by means of a line breaker. Each section is provided with a No. 000 main, as indicated, and these mains are fed by two feeders *1* and *2* running from the power station. The drop under average conditions is to be limited to 50 volts. Each car takes an average current of 20 amperes.

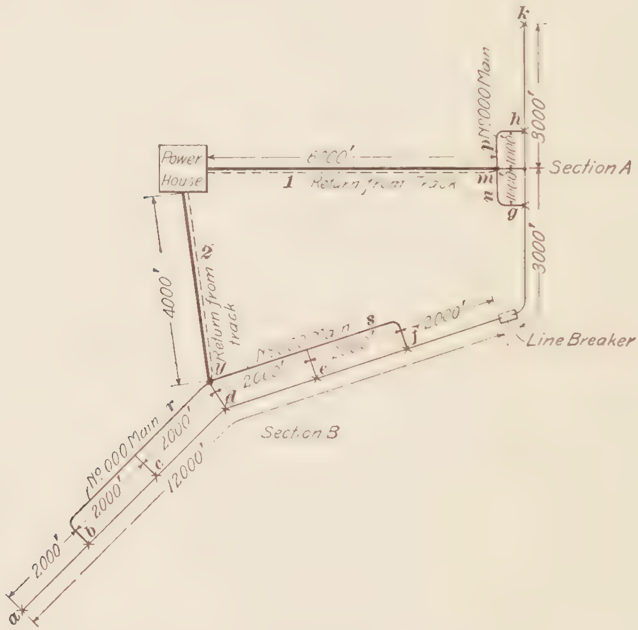


FIG. 6.

SOLUTION.—Since the cars are equally spaced and constantly shifting in position, the drop will vary somewhat, depending on the position of the cars. In order to make things definite, we will assume that the cars are located as shown by the crosses. This will represent a fair average condition, and the drop for other positions will not be greatly different unless the cars become bunched in some particular spot. If we design the feeders so that the drop from the power house to cars *a* and *k* shall not exceed 50 volts, it is evident that the drop to the other cars will fall under the prescribed 50 volts, because cars *a* and *k* are the most distant from the station. No track resistance is specified, so we will make use of formula 3 in estimating the drop in those parts of the circuit that include a track return. We will first take section *A* and determine the size of feeder *1*.

Section A.—The road operates nine cars and is 18,000 feet in length; hence, there will be one car for every 2,000 feet. Section *A* will have three cars and the current supplied by feeder *1* will be 60 amperes. The size of the trolley wire and its distributing main is fixed, so that we must first determine the drop in this part and then see what is left for the drop in the outgoing and return feeders. It is easily seen that return feeders from the track must be used, because the power house is some distance from the track and the ground cannot be depended on to carry the current. The return feeders may be strung either on poles or placed underground. We will first determine the drop from h to k. To do this we have the formula

$$\text{Circular mils} = \frac{14.4 \times L \times C}{e}.$$

In this case, however, we know the number of circular mils in the cross-section of the trolley wire and wish to find e; so, transposing the formula, it becomes

$$\text{Drop } e = \frac{14.4 \times L \times C}{\text{cir. mils}}.$$

In this case, L (distance from h to k) $= 2{,}000$ feet, $C = 20$ amperes, and the circular mils of No. 00 wire = about 133,000;

hence, $$\text{Drop } e = \frac{14.4 \times 2{,}000 \times 20}{133{,}000} = 4.3 \text{ volts.}$$

The drop from the feeding-in point m to the point h is next calculated. The cross-section of the wire carrying the current is that of the main (No. 000) plus that of the trolley (No. 00). The total number of circular mils is then, approximately, $167{,}800 + 133{,}000 = 300{,}800$. The distance is 1,000 feet and the current is 40 amperes;

hence, $$\text{Drop } e = \frac{14.4 \times 1{,}000 \times 40}{300{,}800} = 1.9 \text{ volts.}$$

The total drop from m to k is, therefore, $4.3 + 1.9 = 6.2$ volts. This leaves $50 - 6.2 = 43.8$ volts drop for the outgoing and return feeders combined.

Feeder *1* with its return feeder will have to carry current for three cars, i. e., 60 amperes, and this current must be carried over $6{,}000 \times 2 = 12{,}000$ feet of wire. This part of the circuit will be of copper throughout and the same size of wire will be used both for the outgoing wire and the return. We have, then, using formula **1**,

$$\text{Circular mils (of outgoing and return feeders } 1) = \frac{10.8 \times 12{,}000 \times 60}{43.8} = 177{,}500.$$

A No. 000 feeder comes nearest this, although it may be a trifle small. It might perhaps be better to install a No. 0000 feeder, for the reason that four cars might easily become bunched on section A, and, besides, it is well to have some margin for future extensions.

Section B.—The drop from b to a will be 4.3 volts, that is, the same as from h to k in section A. The drop from c to b will be twice that from m to h, because the size of conductor and the current are the same, but the distance is twice as long. The drop from c to b will, therefore, be $2 \times 1.9 = 3.8$ volts. Car d will cause no drop in the trolley or main, because its current is taken directly from the feeder. The drop from d to c will be that due to 60 amperes through 2,000 feet of combined trolley and main;

hence, $$\text{Drop from } d \text{ to } c = \frac{14.4 \times 2{,}000 \times 60}{300{,}800} = 5.7 \text{ volts.}$$

Total drop from y to $a = 4.3 + 3.8 + 5.7 = 13.8$ volts, and the total allowable drop in the outgoing and return feeders is $50 - 13.8 = 36.2$ volts.

The current in feeder *2* will be that due to six cars, i. e., 120 amperes; the total length of outgoing and return feeder will be $4{,}000 \times 2 = 8{,}000$ feet;

hence, Circular mils (of outgoing and return feeder *2*)

$$= \frac{10.8 \times 8{,}000 \times 120}{36.2} = 286{,}400.$$

This is larger than No. 0000. Two No. 00 wires will give about 266,000 circular mils, but the best plan will probably be to use a 300,000-circular-mil stranded cable, as this will allow some margin on the large side and involve less line work. The return feeder will, of course, also have an equal cross-section.

21. Carrying Capacity of Feeders.—In making these calculations, no attention has so far been paid to the carrying capacity of the wires and cables that have been used. Of course, this point must be kept in mind, because if the lines are simply figured out on the basis of giving the allowable drop, it might happen that the current will be sufficient to overheat the wires. The accompanying table gives the approximate amount of current that the wires may be allowed to carry without causing the temperature to increase much over 25° F. above that of the surrounding air. These

values are given by Mr. H. W. Fisher, of the Standard Underground Cable Company.

No. B. & S. Gauge.	Circular Mils.	Carrying Capacity, With a Rise in Temperature of 25° F., Approximately. Amperes.	No. B. & S. Gauge.	Circular Mils.	Carrying Capacity, With a Rise in Temperature of 25° F., Approximately. Amperes.
Stranded Cables.	500,000	509	2	66,370	124
	400,000	426	3	52,630	107
	350,000	388	4	41,740	91
	300,000	355	5	33,100	74
	250,000	319	6	26,250	63
0000	211,600	275	7	20,820	52
000	167,800	237	8	16,510	44
00	133,100	195	9	13,090	36
0	105,500	168	10	10,380	30
1	83,690	143			

In most cases, however, it will be found that the size of wire necessary to keep the drop within the specified limits will be considerably larger than that necessary to handle the current without overheating. Only in cases where the distances are short is there likelihood of the wire not being large enough. It is always well, however, to compare the sizes obtained and the current that the wires must carry with the values given in the table. If the wires should prove to be too small, the only thing to do is to use a wire that will carry the current safely or else run the risk of the wire overheating. If the larger wire is used, it will result in a somewhat smaller drop, but this will be an advantage, although the first cost of the wire will be a little higher.

22. Effects of Low Voltage.—In all the line and feeder calculations that have been made, the end in view has been to limit the drop to a certain amount. If the drop becomes

excessive, either on account of the feeding system being too light or the load too heavy, it will produce a low voltage at the cars, and this in turn means low speed. It is a well-known fact that just as soon as the voltage on a system becomes low, troubles with the motors and car equipment begin to multiply. There are many cases on record where controller and brush-holder troubles have been very much decreased and where the roasting of field coils, controller blow-out coils, and the throwing of solder out of the commutator connections have been entirely stopped simply by raising the voltage on the line.

Let us suppose that a road having a certain number of cars is operated at, say, 550 volts and on a certain schedule. Suppose that, owing to an extension of the road, the addition of more cars, the deterioration of the track-return circuit, or any other reason, the voltage gradually comes down to 400. This will make a maximum decrease of about 20 per cent. in the running speed of the cars. If the time table is rearranged so that the motormen can run the cars on time with the same ease that they could with the higher voltage, the troubles with the rolling stock will not only not increase, but they will actually decrease, because the lower voltage is not as hard on the insulation and arc-breaking devices and the lower speed is not as hard on the car bodies and trucks.

If, on the other hand, no notice is taken of the gradual decrease in the average line voltage and the same time table is kept in force, the following will be the result: Since the maximum running speed of the cars has been cut down, the motorman must make up time wherever he can. Most of this will be made up at starting and getting the car under headway; part of it will also be made up on curves, crossings, and other places where, under ordinary conditions, slow running would be the rule. At starting, the controller is moved around rapidly and the car takes far more current than it should. This excessive current injures the controller, the commutator, and the brushes. The insulation on the fields becomes roasted and troubles of all kinds are liable

to occur simply because the equipment has to be abused to make the car run on time.

As a practical instance of the result of low voltage, we may cite the following actual case that occurred where two abutting roads used each other's tracks for about $\frac{3}{4}$ mile. Their trolley wires were separated by a line breaker and each road had its own feeder system. On one side of the breaker the voltage was 425 volts; on the other side, 525 volts. As long as each road used only its own trolley wire the high-voltage road had no trouble to speak of. As soon as its cars began to run over the low-voltage road, controller and brush-holder breakdowns set in and continued until two extra feeders were run to the low-voltage side.

The above effects have been noted here simply to show that the question of proper voltage is an important one. It is true that there are many roads operating under an excessive drop, and this in itself is not so bad if the pressure at the station is increased so that the proper voltage at the cars is maintained. At the same time, a large drop means a large waste of power, and the question as to whether it will pay better to lose a considerable amount of power or buy more feed wire is something that must be determined by the relative cost of power and copper.

ELECTROLYSIS.

23. Introductory Remarks.—The subject of **electrolysis** is closely connected with the feeding system, especially the track-return part of it. By electrolysis in this connection is meant the eating away of the rails, underground pipes, or other buried metallic conductors by stray currents from the street-railway system. When electrolysis was first noticed, a great outcry was raised against the trolley roads by gas and water companies, telephone companies, and other corporations owning underground pipes or lead-covered cables. Many lawsuits were brought against electric-railway companies, and this led to an investigation of

the subject. The result has been that electrolysis is not feared nearly as much as it once was, because means have been devised for avoiding it largely or for limiting it to sections where it can be watched or provision made to prevent it.

24. Elementary Principles.—In Fig. 7, *A* and *B* are two iron plates buried a short distance apart in damp earth. If the terminals of *A* and *B* are connected to a dynamo and a current is made to flow from *A* to *B* through the earth, we will find that plate *A* is eaten away or pitted, while plate *B* is not damaged. This is practically the same electrochemical effect that takes place in electroplating, where metal is taken from a plate or anode and deposited on the article to be plated. The point to notice is that wherever current flows *from* a metal conductor into the earth, the conductor is eaten away, but where current flows from the earth *into* the conductor, the latter is not damaged. The rate at which the metal will be eaten depends on the strength of the current. One ampere flowing steadily for 1 year will eat away about 20 pounds of iron or 75 pounds of lead, so that it is not hard to see that the damage due to this effect may be a very serious matter.

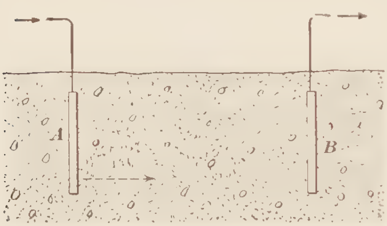


FIG. 7.

25. Electrolysis Due to Railway Currents.—Fig. 8 gives a simple illustration as to how electrolysis may occur in connection with an overhead-trolley system. *T T* is the trolley wire and *R R* the track. Under ordinary conditions, the current is supposed to return by way of the rail, as indicated by the arrows. If, however, there happens to be a pipe *L L* in the neighborhood of the track, and if this pipe offers a ready path for the current, part of the current will leave the rails, as at *I*, enter the pipe and flow out again at *O* to return to the power station. At *O*, where

the current *leaves* the pipe, electrolytic action will be set up and in the course of time will eat holes in the pipe. At *I* the current leaves the rails; hence, the rails will be eaten away to some extent. If the trolley wire were connected to the negative pole of the dynamo instead of the positive, the current would flow out through the track, and whatever corrosion occurred on the pipes would take place at points

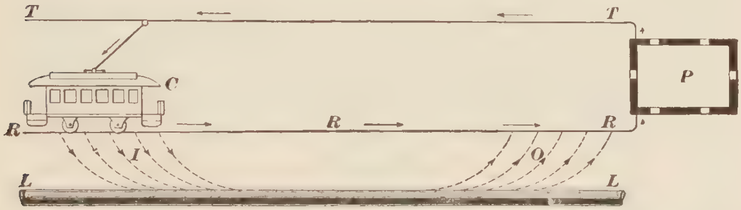


FIG. 8.

removed from the station and would be scattered over a wide area. On the other hand, with the positive pole connected to the trolley, whatever action takes place on the pipes is confined to districts near the power house. These areas are comparatively small, and measures can be taken to protect them. This is the principal reason why the positive pole of the dynamo should be connected to the trolley side of the line.

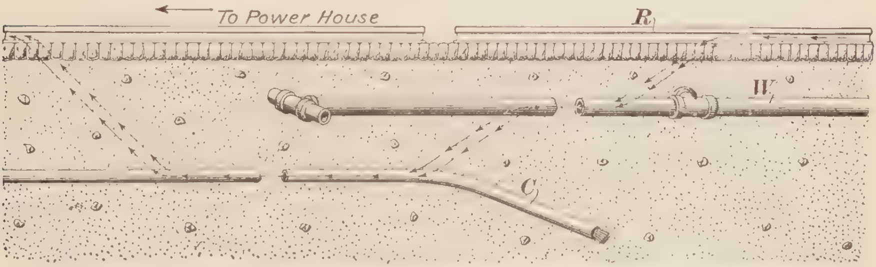


FIG. 9.

Figs. 9 and 10 show modifications of the simple case shown in Fig. 8. In Fig. 9, the current leaves the rail *R*, enters the pipe *W*, and flows through *W* until a better path presents itself in the shape of the lead-sheathed cable *C*. It

flows along *C* until the track presents a better path, when it flows back to the rail again, as indicated by the arrows. Electrolytic action will occur where the current leaves the rail, the iron pipe, and the lead sheath of the cable. Fig. 10 shows a case where a cable and pipe run parallel to the iron rail *A B*, the arrows indicating the path of the

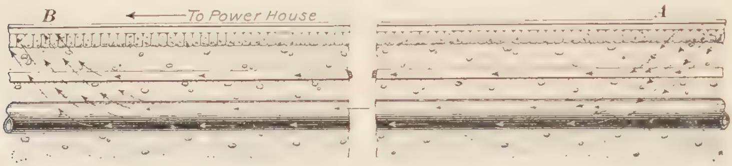


FIG. 10.

stray current. Lead-covered underground cables are particularly liable to damage, because lead is eaten away much more rapidly than iron; moreover, the corrosion never takes place evenly, but in spots, so that the pipe or sheath becomes pitted and is soon destroyed. Wrought-iron pipes are more quickly eaten than cast iron; in fact, the harder grades of cast iron, such as chilled iron, seem to be very little affected.

26. Influence of Resistance of Track Return.—It is easily seen, by referring to Fig. 8, that if the track return is in good condition, there will be little inducement for the current to leave the track and pass through the intervening earth to come back on the pipes. One of the most effective means, therefore, for preventing electrolysis is to see that the rails are thoroughly bonded. With the greater attention that is paid to good rail bonding on modern roads, there has been a corresponding reduction in the damage due to electrolysis.

27. Detection of Electrolysis.—As already stated, electrolysis occurs only when the current flows from the pipe or other conductor to the earth; in other words, the pipe or conductor must be at a higher potential than the surrounding earth. The dangerous points may, therefore, be located by going around to different parts of the system and taking readings of the voltage between the pipes or

cables and the surrounding earth or neighboring pipes. If the pipe is positive to the ground, current will flow from the pipe to the ground; if, on the other hand, the pipe is negative and the earth positive, it shows that the current tends to flow towards the pipe and no harm is being done. After the dangerous localities have been located by means of these tests, return feeders can be run out to the danger points and attached to the pipes and track, so that the current will flow back on these feeders instead of leaving the pipes and causing damage.

28. Prevention of Electrolysis.—The ordinary precautions taken to prevent electrolysis on an overhead-trolley system have already been mentioned. The trouble is first localized near the station by connecting the positive pole of the dynamo to the line; next, the ground-return circuit is made as good as possible by thorough track bonding. Finally, tests are made to locate points where there is danger of electrolytic action and conductors run to these points to convey the current back to the station.

29. Systems Free From Electrolysis.—Systems using the double overhead-trolley and conduit systems, where the rails are not used as part of the return circuit, are, of course, exempt from trouble due to electrolysis. Roads operated by alternating current are also free from this trouble, but such roads are comparatively few in number.

30. Cars Operated on Three-Wire System.—Another scheme for preventing a great deal of the trouble due to electrolysis and at the same time using a higher line voltage is to operate the cars on the three-wire system, as shown in Fig. 11. A and B are the two tracks of a double-track road and c, d the two trolley wires. G, G' are two 500-volt generators connected in series and running the railway on the three-wire system. The track constitutes the neutral conductor, and it is evident that if the load on the two tracks is balanced, no current flows through the rails. The track return is called on to carry only the difference in the load, and as there are four rails to serve as a conductor, there is

little tendency for the current to come back through pipes or other conductors. The use of this three-wire arrangement allows the power to be transmitted at 1,000 volts instead of 500, and therefore effects a saving in copper. The high pressure is, however, objectionable, especially in thickly populated districts, but it seems as if the system would be well adapted for cross-country and suburban lines. The

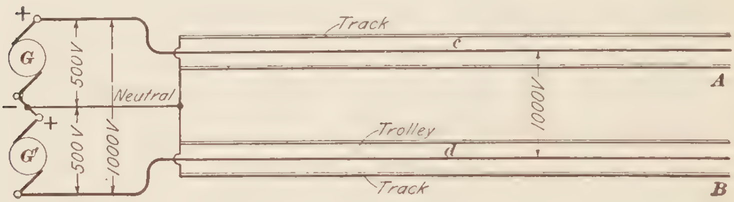


FIG. 11.

saving in copper is not as great as that effected in changing a two-wire lighting system to a three-wire system, because in the simple 500-volt trolley system the track is already utilized, whereas in the three-wire method of operation it is used very little. The saving in copper will, however, be from 20 to 40 per cent., depending on the quality of the track return.

Fig. 12 shows the three-wire system used on a single-track road. The trolley wire is here cut into sections, the length of which depends on the traffic. These sections are connected

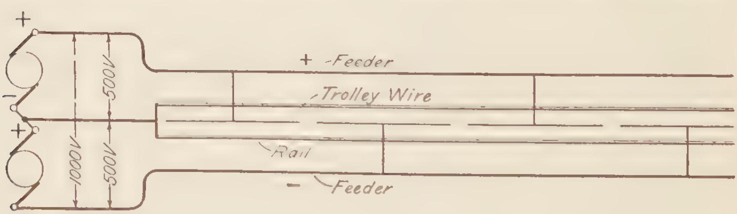


FIG. 12.

alternately to the two sides of the system and the track forms the neutral conductor. By choosing the length of the sections properly, the load on the two sides of the system may be balanced closely enough for all practical purposes.

LINE TESTS.

31. With the ordinary overhead-trolley system it is not, as a rule, necessary to make many tests of the overhead conductors. One side of these systems is always grounded, so that if a ground occurs at any point, due to poor insulation or any other cause, a short circuit results and the fault is either burned out or some indication is given, so that there is little difficulty in locating it. The insulation of the system may be measured by the voltmeter method.

There are, however, two special tests that are sometimes used in connection with electric railways that we will describe briefly. These are tests for defective rail bonds and track resistance.

32. Tests for Defective Rail Bonds.—Rail bonds are liable to work loose in time and develop bad contacts, and it is necessary to have some convenient means for detecting bad joints. Fig. 13 shows one device that may be used for this purpose. It consists of a flat wooden straightedge about 6 feet long provided with three spring contacts *a*, *b*, *c*. When this straightedge is laid on the track, contacts *a*, *b* span the joint and *b*, *c* a fixed length of rail. *V* is a millivoltmeter (a voltmeter reading to thousandths of a volt)

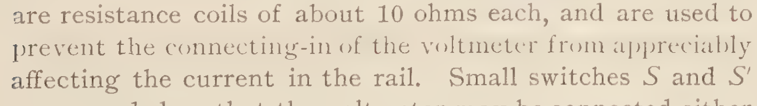


FIG. 13.

connected to the contacts *a*, *b*, and *c*, as indicated. *R* and R_1 are resistance coils of about 10 ohms each, and are used to prevent the connecting-in of the voltmeter from appreciably affecting the current in the rail. Small switches *S* and *S'* are provided, so that the voltmeter may be connected either between *a* and *b* or between *b* and *c*. The voltmeter should have the zero point at the center of the scale, so that the readings will be on opposite sides for currents through the two circuits. Now, when current is flowing through

the rail and joint, the voltmeter reading between *b* and *c* will be proportional to the resistance of the section of rail between *b* and *c*, and when the voltmeter is switched to *a* and *b*, its reading will be proportional to the resistance of the joint. In this way, the resistance of any joint as compared with a fixed length *b c* of rail can be determined, and since the resistance that a good bond should have is known for the particular styles of bond in use, it is easy to determine just about what ratio the two voltmeter readings should bear to each other for a joint that is in good condition. If the reading across the joint is abnormally high as compared with that across the rail, the bond should be repaired.

33. Fig. 14 shows another method of detecting bad joints, which is similar in principle to the one just described. In this case a telephone is used for an indicator instead of a millivoltmeter. The telephone is a good instrument for this purpose, as it is very sensitive and is easily

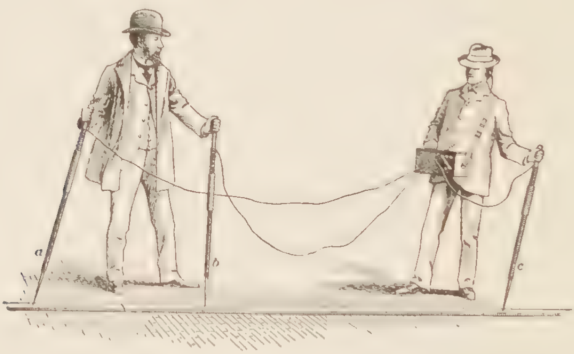


FIG. 14.

carried about. The operator on the left is provided with two poles having pointed metal terminals. Flexible wires lead from these terminals to the box carried by the second operator, who also carries a similar rod connected to the box, as shown. This box contains an interrupter that interrupts the current flowing through the head telephone worn by the

operator, and thus causes the telephone to make a noise. Poles *a* and *b* are placed about 3 feet apart, so as to span the joint and fish-plate. Pole *c* is placed about 4 or 5 feet from *b*. By means of the switch the telephone is thrown first across one span and then across the other, the pole *c* being shifted until the sounds obtained for the two different positions are nearly the same in loudness. The switch on the box is then thrown to the middle position and the position of *c* more accurately adjusted, until little or no sound is heard in the telephone. When this condition of affairs is reached, the resistance of the length of rail between *b* and *c* is equal to the resistance of the joint between *a* and *b*. Since the weight of rail per yard is known, the resistance of the joint may be calculated from the known length *b c*. Usually, however, this will not be necessary, because the test is used principally for locating bad joints, and comparative results are what are looked for more than absolute measurements.

It will be noticed that the above test makes use of the current flowing in the rail, but is independent of the variations in this current, because the same current flows through both rail and joint. The use of the telephone instead of a voltmeter allows the tests to be carried out conveniently and rapidly. Fig. 15 shows the connections of this testing outfit. *A* is the vibrator, *B* the telephone, and *C* the three-point switch.

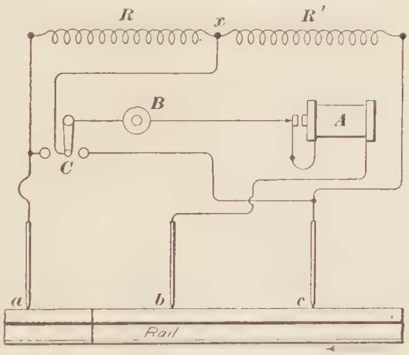


Fig. 15.

R and *R'* are two similar resistances. When the resistance between *a* and *b* is equal to that between *b* and *c*, it is evident that no current will flow through the telephone when *C* is on the middle point, because points *x* and *b* will be at the same potential.

34. Testing Resistance of Track-Return Circuit.—After a road has been in operation some time, it is often found that the drop on certain sections is larger than it should be, and it becomes necessary to remedy matters. The question naturally arises as to whether the track return is at fault or whether more copper is required in the overhead feeders. In order to find this out, it is necessary to know the comparative resistances of the two. If the track resistance is high compared with that of the overhead line, the track return needs attention, and *vice versa.*

Fig. 16 shows one method of measuring the resistance of a railway circuit. *F F* is the feeder running out to the section under consideration and *R R* the rail return. A time is selected at night, when traffic can be kept off the section

FIG. 16.

for a short time, and a water rheostat *W* is connected in series with the feeder *F* and the regular feeder ammeter *A*. The feeding-in point *x* is connected to the track by any convenient means, as shown at *x y*, and a steady current is sent through the circuit *G* + –*W*–*A*–*c*–*F*–*F*–*x*–*y*–*R*–*G*—. The drop through the entire feeder and rail circuit is measured by a voltmeter *V* connected to *c* and *b*. From the readings of *A* and *V*, the total resistance of the feeder and rail circuit is at once determined. The resistance of the feeder *F F* can be calculated from its known length and cross-section, and its resistance subtracted from the total resistance of the circuit will give the resistance of the track return.

The above method of finding the resistance of the track return assumes that there are no bad joints or unusually poor conductivity in any part of the feeder *F F*, but such is

not always the case. If the trolley wire runs back to the power house or if there is another feeder nearby that can be used as a pressure wire, the drops in the feeder and track may be measured separately and an accurate idea gained as to just how the drop is distributed. For example, if the upper voltmeter terminal is connected to the end a of the trolley wire instead of to c, the reading obtained will be the drop through the track alone, because the voltmeter takes such a small current that there will be practically no drop through $T x$. If one terminal of the voltmeter is connected to c and the other to a, the reading obtained will be the drop in the feeder $F F$. This method is the one to be preferred, because it at once gives an accurate comparison between the loss in the overhead work and the loss in the track and shows what part of the system requires attention in order to bring about better working conditions.

AUXILIARY EQUIPMENT.

35. We have already considered that part of an electric railway system that pertains directly to the supply of current for the cars. The rolling stock and car equipment remain to be considered, but before going on to this part of the subject, it may be well to pay some attention to what might be called the auxiliary departments of a road. Under this head may be included car houses or car barns, repair shops, etc. These, while not, perhaps, directly connected with the running of the cars, are at the same time an essential part of the road. Their equipment varies greatly on different roads, so that the descriptions can only be very general in character.

THE CAR HOUSE.

36. The **car house** or **car barn** is a building used for storing cars that are not in use; that is to say, either for storing the regular schedule cars during the hours when they are not in use or for storing closed cars in hot weather

or open cars in cold weather. The ideal arrangement would be to have the repair shops, the car house, the power station, and the general offices all centralized, as it would effect a great saving in time and labor; but, unfortunately, in most cases this cannot be done, especially on large systems. The nature and extent of the traffic dictates the location of the power stations, and the cost of land that of the repair shop and car houses. Of course, in many cases, a large system is the result of the consolidation of several smaller ones, and this always introduces objectionable conditions that cannot be overcome. On the small roads, it is not so difficult to centralize the buildings. On the large roads, it is the custom to have one large, well-appointed repair shop as centrally located as possible in regard to the several depots from which the cars are sent out on their runs. These depots generally constitute a sort of combination car house and auxiliary repair shop, where light repairs are done to avoid sending the cars to the main shop. Such a combination depot should, from the storage point of view, be as nearly fireproof as possible and should have all the facilities for extinguishing a fire.

Where practicable, the tracks should be far enough apart to admit of easy passage between the cars, and the more uniformly the daylight is diffused throughout the building, the better. In some car houses the storage room is all on one floor; this may be the first or second floor, according as the cars to be stored are out of season or are just temporarily out of use. In other storage houses, two or more floors are used, in which case an elevator must be used for handling the cars on the upper floors.

Where the cars must be transmitted to and from an upper story by means of an elevator, it is almost always the case that the stripped or out-of-season cars are stored there. As there is no possible chance of saving the cars in time of fire, there is no objection to setting them on horses or barrels; but where the storage tracks are on a level with a street track, the cars should be set upon temporary trucks, so that at an alarm of fire they can be run out. For ordinary

over-night storage of cars, the practice of having all cars depend on the use of a transfer table to take them to a track that leads to the street is a bad one, on account of the great fire risk. Where practicable, every storage track should lead to the street at one end or the other of the car house. In some houses it is the practice to grade the rails down to the street, so that in case of fire it is only necessary to let off the brakes and the cars will run out. That part of the car house that is to be devoted to light repair work should have every facility for inspection and repair. There should also be a stretch of about 40 feet of double track, where the cars come into the house, provided with a cement or other waterproof floor, draining to the sewer or to a cesspool. This is to be used for washing the cars as fast as they come in for the night.

37. For inspection of trucks and motors there should be **pits** about 4 feet 8 inches deep directly under the tracks, no pit to be shorter than any car that may be placed over it. As to the total amount of pit room required per car, it is a very hard matter to fix between narrow limits, as it depends a great deal on how much trouble the equipments give. A safe value, however, based on long experience with almost all conditions of working with several types of motors and trucks, is 1 linear foot of pit room for each car that runs into the depot; that is to say, a depot handling 100 cars could get along with 100 feet of pit room without a great deal of shifting. The arrangement of this pit room will depend considerably on the arrangement of the tracks in the house. An ideal arrangement would be to have four pits 25 feet long each, or three pits 33 feet long each, according to the length of the cars to be handled. The pits should have cement bottoms and be properly drained. The space between the tracks on the floor level should be boarded, but the underneath space between the pits should be left open.

A couple of shelves and a row of small bins to hold a few of the most commonly used sizes of bolts, nuts, and washers save time and should be placed in each pit. Each pit must

have a *pit jack*, which is a common pump jack with its rack made longer and terminating at the top in a kind of cradle to hold an armature without bruising it. The jack is provided with a pivoted base mounted on a four-wheel truck. The class of work that it is profitable to do at the outside depots is the changing of motor armatures, field coils, brush holders, bearing wheels, and controllers, and the supplying of missing bolts, nuts, washers, and other small parts, together with the general repair and adjustment of brake rigging. A hand forge and a blacksmith that can make himself useful in other lines of work are usually necessary in any depot running out more than 30 cars. A small drill press and lathe for boring bearings and for drawfiling or turning down armature bearings to standard size, or putting on heads or bands, will soon pay for themselves in a depot shop if operated by a man that can make himself otherwise useful.

38. Wiring of Car House.—The wiring of the car house is a simple matter, but its plan depends on the track layout of the house. Every track should have a trolley wire over it. The house trolley wiring, as a whole, should be separated from the main line outside by means of a line circuit-breaker; it must then be connected to the street wires by means of a jumper that passes through a switch placed outside of the building, so that in case of fire the whole house wiring can be disconnected. The wires in the house are supported on barn hangers made for this class of work (see Fig. 17). The hanger is fastened to the house beam by means of lugs *b*, *b*, the trolley wire being fastened to ear *c*. In iron barns, the hanger must be screwed to wooden blocks supported from the iron girders. In some

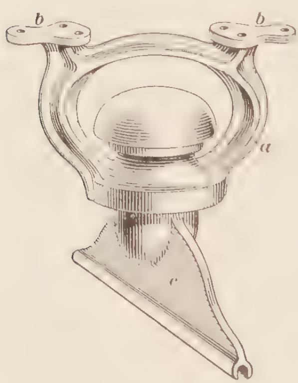


Fig. 17.

barns, the trolley wire is run in an inverted wooden trough placed over it, and the hangers are screwed to the bottom of this trough. In such a case, the trough generally catches the wheel if for any reason it leaves the wire; it also serves as an insulated support for the wheel at night and obviates the necessity of tying down the pole where such a rule is in force. In a metal barn, it makes it impossible for the trolley pole to come in contact with the metal structure and the live wire at the same time if the pole should fly off the wire. Sometimes at short curves under very low structures it is the practice to do away with the trolley wire altogether and replace it with an inverted brass or copper trough, in which the trolley wheel rolls along on its flanges.

39. When the car house is situated near the street line, the several tracks running into it should not start from the main line, but a siding *s*, Fig. 18, should be laid out so that through cars need not go over so many switches. Those from the left pass over the switch *a* only, those from the right over *b* only, saving some amount of wear and tear on car wheels and greatly prolonging the life of the switches.

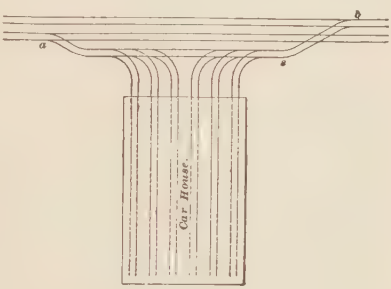


FIG. 18.

THE REPAIR SHOP.

40. The repair shop is the place where all heavy repairs and alterations are made. A well-appointed repair shop should include a *pit room*, *machine shop*, *carpenter shop*, *mill*, *blacksmith shop*, *paint shop*, *winding room*, *commutator room*, *controller room*, and a *wheel-grinding annex*. In the pit room, all truck and motor repairs are made. In the machine shop, all general machine work is done, such as fitting bearings, turning down commutators on the shaft, recutting

bolts, etc. In the winding room, fields, armatures, armature coils, etc. are wound, insulated, and baked. In the commutator room, the parts of the commutator are assembled and the finished article tested. In the controller room, controllers, switches, resistances, etc. are repaired. In the mill, the repair parts for car bodies are made. The best place for the machine shop is in the rear end of the pit room, and the worst place for the forges is next to the paint shop. The armature room should not be exposed to the dust from an emery wheel, and it is equally important that the commutator room be well protected. The shop building should be a substantial fireproof structure and every effort should be made to have good light throughout.

41. The Pit Room and Machine Shop.—The number and length of the pits depend on the nature of the work to be done and the number of cars to be handled. If no armature, field, wheel changing, etc. is done at outside depots and must be done at the main shop, 1 linear foot of pit room per car is about right. The pit rails should be laid on stringers supported by brick piers, and the space underneath between pits should be left open, so that a man can go from one pit to another without going up on the floor. There should be means provided for raising the car bodies off the trucks quickly and with as little labor as possible. A cheap way to do this is to hang over each pit three rails, along which chain falls are free to move from one end of the pit to the other. The center overhead rail is over the center of the pit, and its hoist is used in the truck and motor work after the car body is up. On each of the two outside rails are two chain hoists, and the hoist rails are just far enough outside of the track rails to have the hoists clear the car under all conditions. The system is made more efficient if the hoist rails of neighboring pits are connected at the ends, so that a set of falls can be run over from one pit to another. Only one set of falls is required in each pit, for if more are needed, the car bodies can be set on barrels or horses to free the falls. To avoid the use of extra long hoist chains, the

falls are suspended from the carriages by long double eyebars. In conjunction with the hoists are used two wooden beams with an eyebolt in both ends to take the **S** hook that engages the hook on the chain fall; 2,000-pound hoists are heavy enough for single-truck cars, but in case any extra heavy lifting may arise, it is well to provide one pit with 4,000-pound hoists. With such an outfit, two men can raise a single-truck car in about 5 minutes after the body bolts are out and the motors and brake rods are disconnected. The chain falls should be oiled once a month. It is becoming common practice to provide car shops with an air compressor and reservoir, the air to be used in blowing the dust out of motors, controllers, etc.; in such a case, the compressor, or air pump, is driven by a motor. The air pump stores the air in a main reservoir that is piped to auxiliary reservoirs situated at the points where the air is to be used. Air has proved to be the best thing for cleaning purposes, and in the several instances where it has been used as a means of operating lifts to raise cars and to handle heavy work around the lathe and boring machines, it has scored an equal success.

42. The Machine Shop.—In laying out a machine shop, two important points must be kept in mind: the machines must be so disposed as to admit of having a good light thrown on the work and at the same time must take up as little floor space as possible. The number and kind of machines to be installed depend on the class of work to be done. There should be enough machines so that the work may not be held back for want of them, but at the same time there should be no more of the same or similar kinds than can be kept busy. The repair shop must frequently work overtime, and on this account it is advisable to have it run from a small independent motor, so that in case one or two machines have to be used on overtime, it will not be necessary to run the whole repair shop.

The machines necessary to equip a machine shop are about as follows: One lathe to take an axle with the wheels on it; one smaller one to take armatures and bearings; one

speed lathe; one metal saw; one large and one small drill press; one planer and shaper; one bolt-cutting machine, with right- and left-hand dies; one milling machine; one wheel press; one axle straightener; emery wheels; one grindstone; one power hack saw; one ratchet drill; one punch press; and one power hammer, usually in the blacksmith shop. On a large road, the regular shop work, together with that of power houses, line, and track, will keep the above equipment busy most of the time. On a small road, some of the above might be omitted. The machine-shop practice should be managed so as to do the best and safest work with the tools and stock in hand. The idea of interchangeability of parts should be pushed as far as it will go, even if some other things must be sacrificed.

43. The Winding Room.—As good a place as any for a winding room is in a gallery built around the wall above the machine shop, but a great many object to this plan on the ground that all cores to be wound and wires for winding must be elevated to the gallery. This is true; and where there is plenty of room on the ground floor, it is best to do the winding there; but where space is limited, the above location is a good one, for in case the winding-room motor gives out, there is the shafting below to fall back on. If ground space is available, it can be put next to the machine shop, being separated from it by a fireproof, self-closing door. The machine-shop shafting is extended through and made ready to couple on in case of a breakdown. The size of the armature room required for a given number of cars depends, of course, on many local conditions, among which can be mentioned the type and age of the equipment in use; the condition of the track and line work, and therefore, to a degree, the constancy and value of the normal voltage maintained on the line; the number of different kinds of motors in use and their adaptability to the class of work they are called on to do; the competency of the motormen who handle the cars; and a number of other causes.

For a road operating 100 cars or over, from 6 to 8 square

feet of floor space per car should be sufficient for the winding room. For a small road, the space required per car would be much larger. Every winding room that does all its own work, i. e., carries out all the processes of winding and does not buy its armature coils ready-made, should be equipped with about the following: One machine for putting bands on armatures; one field-winding machine; one armature-coil winding machine with a coil former for each type of armature; one gasoline stove, brick-enclosed, with the tank well removed and enclosed (gas is better and safer when it can be had), for heating soldering irons; a device for pulling off commutators (the pinions should be removed before the armatures are sent in); racks for holding rolls of insulation; stands for holding armatures in course of winding; one machine for cutting insulation; one machine for pressing coil papers; one coil press for each kind of coil; ample facilities for dipping the coils in varnish or some other compound; racks for holding completed armatures; an oven or its equivalent for baking armatures (it can be either steam heated or heated with street-car heaters). If the armature coils are dipped in an air-drying compound, no oven is needed, because the armatures themselves and the fields and other coils can be baked by sending a current through them; but if the armature coils are to be dipped in varnish—a much better practice—an oven must be provided, and it might just as well be large enough to bake everything.

The winding room should be provided with substantial patterns of every standard piece of insulation used in the place; one set of these should be hung in a convenient place; a duplicate set should be kept under lock and key, preferably in a fireproof place.

44. The Commutator Room.—The commutator room should be in charge of a good mechanic, and should have in it a lathe, a drill press, a milling machine, and a gas or gasoline oven for baking the commutators. It should be provided with a full line of gauges for the several kinds of mica bodies used and taper plug gauges for the shaft hole bored in the

shell. In modern practice, commutators all fit on a tapered seat on the armature shaft, and it is essential that the commutator should go on just so far and no farther. There should be provided a device for tightening up the nuts without twisting the commutator bars out of line. There must be an adequate supply of assembling rings and the proper wrenches for adjusting them; and no emery wheel should be allowed in the commutator room. The most natural and convenient locaticn for the room is next the winding room. The commutator room should be enclosed, but should have the best possible light and ventilation.

45. The Controller Room.—There is no particular condition to be fulfilled in selecting a site for the controller room. A location just off the machine shop, where it will be convenient to the machines, is as good a place as any.

46. The Mill and Carpenter Shop.—The mill is the room in which the wood-working machines are placed. The carpenter shop is the room where the cars are run in for general body repairs. There is no reason why they should not both be within the same enclosure—the mill at one end and the carpenter shop at the other. The best place for them is between the machine shop, pit room, and paint shop, a line of single or double track running through, so that a car can come in at one end of the building and go out at the other. In the mill there should be a planer, a boring machine, a lathe, a band saw, a circular saw, and a grindstone. The mill should be run from its own motor or from the one in the blacksmith shop. In either case, the motor should be caged off to save it from the dust and should be cared for more than the others.

47. The Paint Shop.—The paint shop should be at the extreme rear of the main shop and should have free access to the street; it should be provided with as many doors on the street side as there are tracks, so that in case of fire the cars can be run out without any shifting or transferring. The paint shop should receive only cars that have been repaired and are ready to run on the road except for the

painting. This being the case, each track in the shop should have a trolley wire over it, the whole system of trolley wires being kept cut out by means of a switch except when they are to be used. Of course, in cases where open cars are painted in the winter and closed cars in the summer, and there is but a single set of trucks for the two sets of car bodies, it will be necessary to run the bodies in on temporary trucks. Under no circumstances should the car bodies be set on horses or barrels in the paint shop. The risk of fire is too great; they should always be on temporary trucks, and where possible, at the head of each line of cars should be a car fully equipped, so that in case of fire they can be all coupled together and towed out of danger. Another good plan is to have the tracks down grade out of the house, so that when the brakes are released or the chocks removed from the wheels, the cars will run out by gravity. On account of the great fire risk incidental to the storage of so many inflammable materials, oils, varnishes, etc., there should be an absolutely fireproof wall between the paint room and the rest of the shop, communication between the two shops being only through self-closing fireproof doors. As a prime precaution against fire, the building should be of brick, with an iron roof and a cement floor. The floor should be graded to gratings that lead to the sewer or to a cesspool and the roof should be designed to give the best possible light and ventilation. All inflammable materials should be kept in a small, absolutely fireproof room that will admit barrels, etc. without trucking them the entire length of the paint shop. The question of fire risk in a paint shop is a serious one, for the reason that the shop is generally full of cars that will burn quickly if once started.

48. The Blacksmith Shop.—The blacksmith shop must be located where the coal dust and gases from the forges cannot reach the paint shop. If there is a cellar with a good light and a dirt floor, it makes a good place for this shop In the blacksmith shop should be at least two forges, anvils,

and a blower. One forge should be provided with an ordinary bellows all ready to be connected on, in case anything should happen to the blower or to the motor from which it is run. Besides the usual complement of forge tools, there should be a machine hammer, shears, and a drill press.

49. The Grinding Room.—If the brakes on a trolley car are applied too hard or if for any other reason the car skids along the track, flat spots, or **flats,** as they are called, are found on the tread of the wheel. These make the wheels pound on the rails, and unless they are removed by grinding or a new wheel put on, the trouble is liable to go from bad to worse. Practically all car wheels are of chilled cast iron. In the molding the tread of the wheel is chilled so that the iron is very hard for a depth of $\frac{3}{8}$ or $\frac{1}{2}$ inch. If the wheel is ground down so that the chilled portion is ground through, there is no use in doing anything further with it, as the iron under the chilled part is too soft to last any length of time. Flats are removed by means of a grinder, which is a device for holding a revolving emery wheel against the tread of the wheel to be ground. The wheels may be ground either in place on the car or separate from the car. The car-wheel grinder can, as a rule, be used to greater advantage out at one of the depots, if the wheels are to be ground on the car; this is undoubtedly the best practice, but it is not always followed. Where the wheels are taken out to be ground, there must be extra means provided for driving the axle, whereas, if ground on the car, one of the car motors can do the work. In either case, the car wheels should make from 20 to 40 revolutions per minute, and the speed of the rim of the emery wheels should be about 5,000 feet per minute. There are several types of car-wheel grinders on the market, and they are all good enough to soon pay for themselves. In general, a grinder must have two hardened centers supported in a substantial frame on both sides of the track; these centers must be movable up and down, so as to meet the requirements of different sized wheels. If the wheel is so small

that the emery will not reach it when the axle is swung on the straight centers, drop centers can be used, but this is seldom necessary. The emery wheels must admit of being fed to and from the wheel and also across the wheel. The bearings must be protected from the flying dust or they will soon be cut up.

If a car is brought in when the flat begins to sound, it can be ground in from 20 to 50 minutes. Even if it takes 2 hours to grind a pair of wheels, it is profitable to do so provided the result of the grinding is not to bring the tread down below the chill. This condition can be ascertained in the course of grinding by knocking the tread of the wheel with a hammer; if the chill is gone, the hammer will easily make a dent. This should also be tried before the axle has been centered. As a rule, one wheel on an axle will be found to be a good deal flatter than its mate; this is due to the fact that on most roads sand is applied to the rail by means of a sand box on each car, and it is always the wheel on the sand-box side that has the deepest flat, because in most cases the flat is due to locking the wheels before applying the sand and then sliding the locked wheels into the sand. Experience has proved that trouble from flat wheels can be to a great extent eliminated by sanding either one or both rails from a sand car; this applies the sand continuously and lessens the chances of the car wheels beginning to slide. Notwithstanding that one wheel may need more grinding than the other, they must both be ground down to within $\frac{1}{16}$ inch of the same diameter. When one wheel is larger than its mate, there will be more or less slipping, and this develops more flats. To grind the small wheels on double-truck cars, a device must be rigged up to turn them, as they have no motor of their own to do it. There has been a great deal of discussion as to whether it pays to grind car wheels or not, and it is safe to say that it pays to grind some wheels, while others it does not. On the whole, a car-wheel grinder will soon pay for itself in many ways if the wheels are brought to it when they should be.

ELECTRIC RAILWAYS.

(PART 5.)

MOTOR CARS AND THEIR EQUIPMENT.

1. General Description of Equipment.—As a rule, the term **rolling stock** as applied to an electric railway is taken to mean the car bodies and trucks, including sweepers and snow plows. Under this head we will also consider the motors, controllers, and other devices necessary for the operation of the cars.

Besides the car body and truck, with its brake equipment, an ordinary trolley car is provided with *motors* (usually two or four per car), two *controllers*, two *canopy* or *hood switches*, one *lightning arrester*, one *fuse block*, one *trolley base*, and one *pole*, with its *harp* and *trolley wheel.* These various devices will be described in detail later. It is now becoming common practice to equip cars with *circuit-breakers* instead of canopy switches and fuse blocks. The equipment also includes one or more *lighting circuits*, and in many cases a *heating circuit* also.

CAR BODIES.

2. The **car body** constitutes the main part of the car and is mounted either on a single truck or on two trucks, depending on its length. Car bodies are made in a large variety of styles. Some are open for summer use, others are

For notice of copyright, see page immediately following the title page

closed, and others are a combination of the two. They are made in lengths from 18 or 20 feet up to 40 or 50 feet. The larger cars usually have the seats arranged crosswise, like an ordinary railway coach.

3. Selection of Car Body.—The selection of the cars for any given road is a matter that requires careful attention. No fixed rules can be laid down to govern the selection of the car body in all cases, because conditions vary. A body that is adapted to one place and condition of service might fail entirely to meet the requirements elsewhere. In some places, open cars can be used the year round, while in other sections there are only a few days in the year when closed cars are uncomfortable. The average conditions call for both open and closed cars, and much attention has of late been paid to the question of devising a car that can be made an open car in warm weather and a closed one in cold weather. The result of much study, experiment, and expense has been the so-called *convertible* or *combination* car, a type which all car manufacturers now make. The nearest approach to a solution of the problem of producing a combination car that is as good in hot as in cold weather is found in the car that is partly open and partly closed. This car has the advantage that it is not only adapted to hot and cold weather, but to rainy weather as well. It has the disadvantage that in no kind of weather does it, as a rule, carry a full load, except during the rush hours, so the power house must carry just so much dead weight over the road. The convertible cars, with removable or sliding panels, can be hardly said to have had a fair trial yet, but there is no doubt that it would be a great saving for a road to have a set of cars that could be run with perfect comfort to the passengers all the year around. It means that little more than half the number of cars need be bought and maintained; also, that every car on the road would at all times be equipped and ready to run.

Cars are constructed according to many different designs, depending on the particular uses to which they are to be

put. The single-truck four-wheel car is fast giving way to double-truck eight-wheelers, because a single truck, on account of the limited wheel base, cannot well accommodate a car body over 20 or 22 feet long, and it has been found that in most cases it pays better to run long cars at long but cer tain intervals than to run short cars at shorter intervals. The most economical practice of all, from the energy point of view, is to run **trailers.** A trailer is a car similar to a motor car, but it is lighter and is not equipped for running itself. On account of the trailer being so light, the ratio of live weight to total weight carried is very much increased, and also the trailers can be left off when they are not needed. But unfortunately the use of trailers increases the number of accidents and consequent damage suits, and these more than offset the value of the power saved.

The point must often be decided as to whether single-truck or double-truck cars should be purchased for a road. It can be safely said that if there is the least doubt as to which to buy, give the preference to the double-truck car. There is nothing so attractive as a well-built and well-appointed double-truck car. This type of car is easier on the car body, easier on the line work, easier on the track, and last, but not least, it is easier on the passengers. Actual statistics have shown that the introduction of the double-truck car will create travel. Being higher from the rail and longer than the single-truck car, it takes longer to load and unload passengers, and for this reason is not adapted to local runs, where the travel is heavy and the stops frequent. This, of course, does not apply to open cars, where ingress and egress are just as free as on a single-truck car.

TRUCKS.

4. The main requirements of a good truck are that it be easy riding, durable, have few parts, wearing parts easily replaced, and wheels easily changed. The trucks must be entirely self-contained; that is, the one framework must

include the wheels and axles, the brakes, motors, and driving gear. This in reality constitutes the car, for the car body above is merely a framework to hold and shelter passengers, having none of the vital parts necessary to operation. The fact must not be overlooked, however, that the car body has to stand severe strains on account of the rapid acceleration at starting and an equally heavy strain when the brakes are suddenly applied in stopping; so that this portion of the car must be carefully designed or it will not last long.

5. Classes of Trucks.—Trucks are of two kinds: **single trucks** and **double trucks.** Double trucks are of two kinds: *ordinary double trucks* and *maximum-traction trucks.* A single truck has four wheels, takes a single motor on each axle, and there is one truck to a car. An ordinary double truck has four wheels, all the same size, can take a motor on each axle, and there are two trucks to a car. A maximum-traction truck has two large wheels and two small ones, the idea being to throw most of the weight on the large wheels, to whose axle the motor is hung and geared. The weight on the small wheels is regulated by means of a compression bolt and spring, just enough compression being put on to keep the small wheels on the rail when rounding curves. As a rule, the large wheels take about 70 per cent. and the small ones 30 per cent. of the total weight. Experiment has proved that for a given weight of car, the maximum-traction trucks do not require as large an expenditure of energy as a single truck with a 7 foot wheel base. The single truck, being more rigid, binds more in curves and does not equalize as readily as the maximum-traction truck, with its shorter wheel base. The ordinary double truck equipped with a single motor has the disadvantage that the driving power is all on one axle, while the weight is divided between two. The result is a tendency for the driving wheels to spin when called on to do heavy duty, because the traction, that is, the friction between the wheel and the rail, is not great enough. By putting a motor on each axle, making four motors to the car conditions are much improved.

Neither maximum-traction nor ordinary double trucks are as well adapted for use on an icy rail as the single truck. A single truck will go up an icy grade that neither of the other trucks can ascend.

The car body is rigidly bolted to a single truck by body bolts passing through the car sills and the top rail of the truck's side frame. Double trucks are attached to the car body by means of center bearings and pins, around which the truck turns as a center. Part of the weight is sustained and the car body kept balanced by the **rub plates,** which are circular pieces of brass that engage mates attached to the car body. These rub plates should be kept well greased. Cars mounted on double trucks sit higher from the rail than single-truck cars, because the body of the car has to clear the wheels and motors. In open cars the truck wheels have to clear the side steps, so that in some cases two steps must be used.

6. Types of Trucks.—Fig. 1 is a type of single truck; Fig. 2, an ordinary double truck; Fig. 3, a maximum-traction truck. In Fig. 1 the motors are supported by the suspension bars b, b, and these bars are in turn supported by the springs s, s resting on the side frame of the truck. The method of mounting the motors will be explained more in detail when the subject of motors is taken up. Since it is advisable to support the motor on springs, it is, of course, equally necessary to provide a flexible support for the truck frame and car body. For short cars, springs placed close to the wheels would be sufficient, although such a construction would have little merit. The reason for providing a longer spring base is to prevent oscillation, which is unpleasant for the passengers and hard on the car body. The oscillation when excessive diminishes the traction on the rising end of the car and causes the wheels to slip. For these reasons, the spring base is extended by adding extra springs at S_1, S_1. The car wheels generally used with such trucks are 30 or 33 inches in diameter, and the trend of present practice is towards the larger size, because it is heavier, raises the

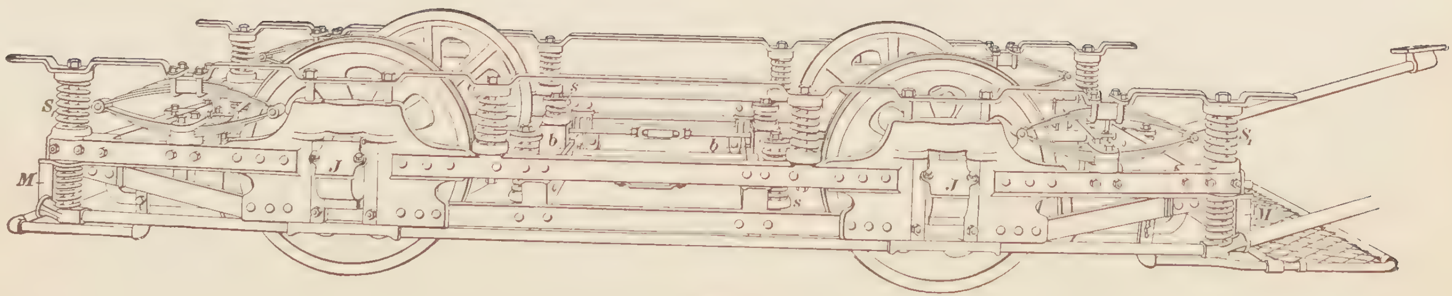


FIG. 1.

bottoms of the motors farther from the paving, allows higher speed, and gives less trouble from breaks and flats. The axle bearings are outside of the wheels, to give stability to the car body, the journal-boxes *f* being free to move vertically through a short distance controlled by a heavy coil

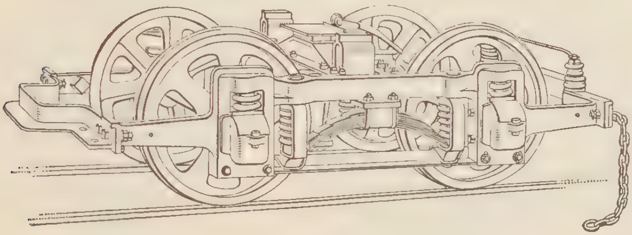


FIG. 2.

spring or rubber washer. Rubber does not amount to much as a cushion after it is old, because it becomes very hard.

Fig. 4 shows a larger view of the bearings used on a single-truck car; *a* is the journal and *b* the bearing brass, which is on the upper half only, because the thrust is all in

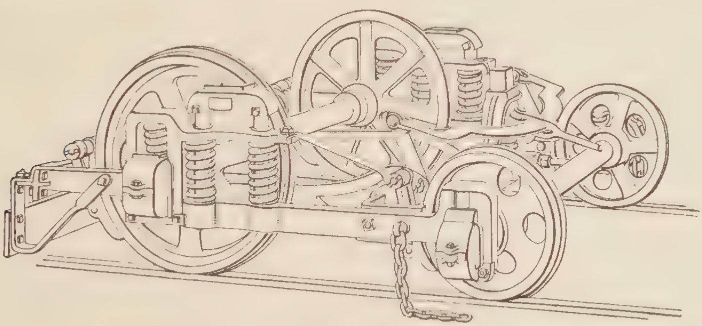


FIG. 3.

one direction. This brass presses against the box casting *c*, which in turn bears up against the spiral springs *s*, that are held in a socket in the frame *f*, as indicated in Fig. 4. By removing the piece *d*, the frame can be lifted clear of the axles. The journal is lubricated by means of waste *g* in the

lower part of the casing. This waste is kept soaked with oil and effects the lubrication in the same manner as on

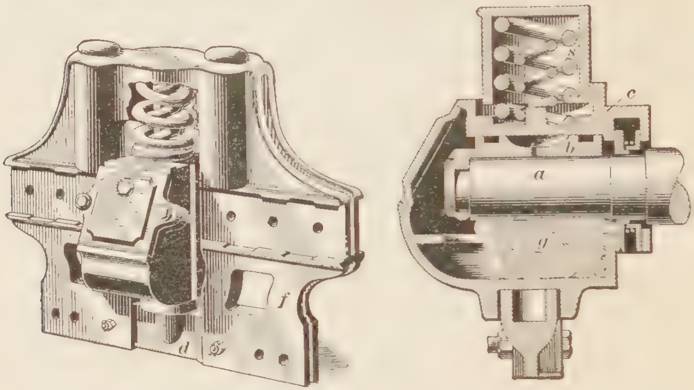


FIG. 4.

ordinary railway cars. To guard the wheels against obstructions, the **pilots** *M*, *M*, Fig. 1, are bolted securely to the frame at a sufficient height from the track to avoid touching the rails.

7. The **wheel base**, that is, the distance between wheel centers as measured along the rail, should be long enough to support the car body without excessive oscillation, but not so long as to bind on curves. Any car body that calls for a wheel base of over 7 feet should be provided with double trucks. Excessive length of wheel base not only wears out the rails and wheels, but increases the power required to pull the car around a curve. If it takes a pulling force of 500 pounds to pull an 8-ton car with a 7-foot wheel base around a curve whose radius is 50 feet, it will take a pulling force of only 350 pounds to pull the same car around the same curve on a 4-foot base. To pull the same car around a curve of 100 feet radius on a 7-foot wheel base would take a pull of 255 pounds, and on a 4-foot base a pull of 185 pounds. The difference in the pull required on the two bases on the 100-foot curve is much less than it is on the 50-foot curve, which goes to show that the greater the

radius of the curve, the less difference does it make what the wheel base is. It is evident, then, that in laying out a road, all the curves should be made of as great a radius as possible; and in buying trucks for a road already installed, the radii of existing curves should be consulted. To enable cars to round curves with the least effort and to save the rails and flanges, curves should be kept clean and well greased. Other points to be considered are in regard to the treads and flanges of the wheels; on them depends very much the ease with which a car will take a curve. The treads should not be so wide that they run on the paving outside of the track, and the shape, depth, and width of the wheel flange should be governed by the shape, depth, and width of the rail groove.

ELECTRICAL EQUIPMENT.

8. The electrical equipment of a trolley car includes several different devices. Some of these, such as the motors, controllers, etc., are concerned directly with the operation of the car. Others—for example, the lightning arrester, fuse box, and hood switches—are more in the line of protective devices. Before considering these various parts in detail, we will glance briefly at the general equipment of a car by referring to Fig. 5. This shows an ordinary 18- or 20-foot car with the details of the truck omitted, in order to show the location of the motors m, m_1. Practically all trolley cars are equipped with at least two motors, and many of the larger cars using double trucks are equipped with four motors. The method of speed control now in use requires at least two motors, as will be shown later. The two motors m, m_1 are hung on the inside of the two axles and geared to them as shown at a, a_1. The speed of the motors, and hence that of the car, is controlled by means of the two **controllers** c, c_1 mounted against the dash irons i, i and operated by the handles n, n_1. When

starting the car, it is necessary to insert resistance in the circuit to prevent too great a rush of current. This resistance is only in a short time and is not supposed to be used when the car is under headway. The **resistance boxes** r are hung under the car, wherever there is the most room for them, usually about in the location indicated, for an ordinary single-truck car. The **lightning arrester** LA and **fuse box** FB are generally attached to the under side of

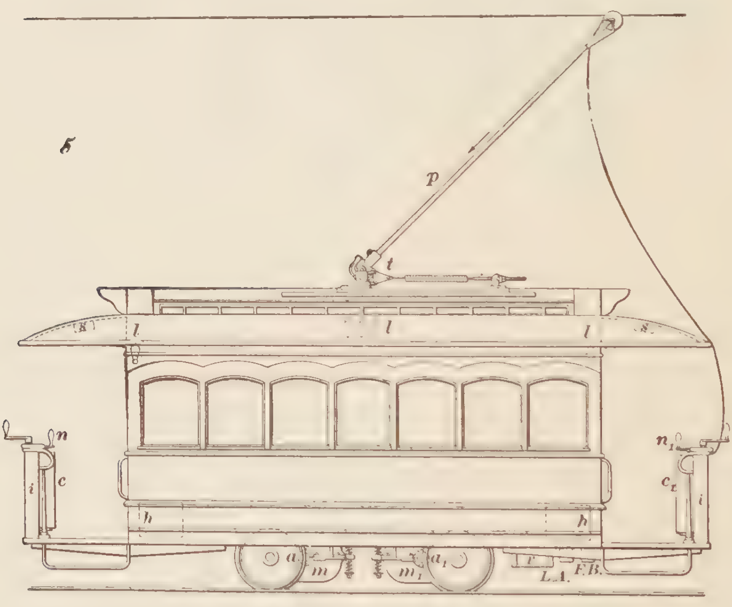


FIG. 5.

the car sill. The **hood switches,** or **canopy switches,** are mounted under the hood, as shown at s, s. In case circuit-breakers are used in place of ordinary hood switches, they are generally placed at s, s and the fuse box is dispensed with. The **trolley pole** p is attached to the **trolley base** t, which is secured to the top of the car. The car is lighted by lamps l, l, l and is heated by means of electric heaters h, h placed under the seats.

METHODS OF CONTROL.

9. It has already been shown that the speed of a motor may be controlled by inserting resistance in series with the armature, thus cutting down the E. M. F. applied to the machine. Before going any farther, it will be well to lay stress on the points that trolley cars are supplied with current at approximately constant pressure, also that the motors used are invariably series-wound. In other words, the armature and fields are in series with each other and the current that flows through one flows through the other also. Shunt motors and compound-wound motors have never been used to any extent for street-railway work.

RHEOSTATIC CONTROL.

10. Since the speed of a series motor run from constant-potential mains may be regulated by inserting a resistance in series with it, the first method adopted for regulating the speed of cars was to mount a **rheostat,** or variable resistance, under the car and have things arranged so that this resistance could be cut in or out by means of the controller at either end of the car. This is known as the **rheostatic** method of control. It can be used with one or more motors, but it is now very little used for regular street-railway work, because it is wasteful of power, especially at the lower speeds. It has, however, some advantages, and it is used in those cases where only one motor is to be controlled and where gradual variations in speed are desired. It is used quite extensively in connection with mine-haulage plants and hoisting apparatus; also for any cars operated by a single motor; but its application to regular street-railway work is now very limited.

On account of the somewhat extended use of rheostatic control in connection with haulage and hoisting apparatus, some of its more important features will be considered briefly. This will also serve as a good introduction to the

more widely used series-parallel method, which will be described later.

11. Old-Style Thomson-Houston Rheostat.—When the rheostatic control was first introduced, a rheostat similar to that shown in Fig. 6 was used. The figure shows the device upside down from the position it occupies on a car. *F*, *F*, *F* are feet cast on the frame; these feet are drilled and provided with insulating bushings, through which pass the three bolts that secure the frame to the under part of the platform. *T* is a drum on which works a chain attached to a sprocket wheel connected to a rod on the upper end

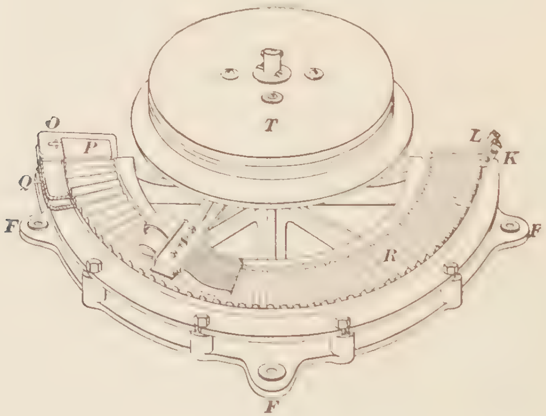


Fig. 6.

of which rests the controller handle. The sprocket wheel is smaller than the drum, so that in order to move the trolley contact shoe *S* from the off-position *O* to the on-position *L*, it is necessary to give the controller handle from two to three complete turns. This insures a smooth handling of the car and makes the controller easy to work. *R* is the resistance, which is made up of stampings of sheet iron insulated from one another by sheets of mica. The iron stampings are not entirely insulated from one another, but are sufficiently longer than the mica sheets to allow

their ends to touch, thus forming a continuous band of metal with several hundred joints in it; the radial rib-like-looking segments sticking up so plainly are iron castings built up with the stampings and mica plates, and are provided in order that the shoe *S* may make good contact. At (*a*), (*b*), and (*c*), Fig. 7, are shown, respectively, the iron stamping, the mica plate, and the cast-iron contact rib. *K*, Fig. 6, is a copper rib that marks the position in which the shoe cuts all resistance out of the rheostat; *L* is a second copper rib that cuts a shunt into circuit as soon as it makes contact with the shoe. These two ribs *L* and *K* are made of copper to improve the shoe's contact in the final or running position, the two forming a kind of copper cradle for the iron shoe to rest in. *P* is an iron contact plate at the off-position, to improve the magnetic circuit excited by the blow-out coil *Q*, and is provided to extinguish the arc that occurs when the current is shut off.

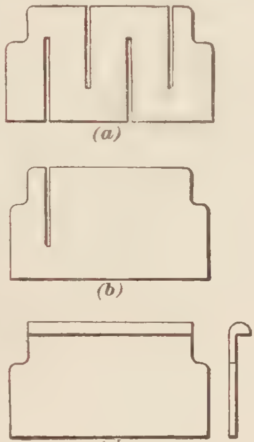


FIG. 7.

12. In addition to the rheostat, it is necessary to provide a reversing switch, so that the direction of motion of the car can be reversed when desired. Fig. 8 shows the connections for simple rheostatic control using an ordinary **reverse switch,** as the reversing switch is commonly called. This switch is operated by a handle on each platform, and the reverse switch and its connections should always be arranged so that when the handle of the reverse switch points "ahead," the car will move ahead, and *vice versa.* In Fig. 8, *T* is the trolley; *F B*, the fuse box; *L A*, the lightning arrester; *T'*, the trolley connection on the rheostat; *S*, the contact shoe that makes contact first with plate *P*, and can be moved around on resistance *R* between the limits of plate *P* and terminals *K* and *L*; *F* is the motor

field; *X*, the reverse switch, to the two top binding posts of which the armature *A* is connected; *G* is the ground wire, to which are connected the ground splices from the reverse switch and from the lightning arrester. When *S* makes contact with *P*, the ordinary path of the current is *T–F B–L A–T′–S–P–R–K–F–2–3–A–4–1*, through the ground wire, to the ground at *G*. If the rheostat arm is turned around until the shoe *S* reaches the dotted position *S′*, and that part of the resistance that has been passed over, marked *r*, cut out, a larger current passes through the motor, making

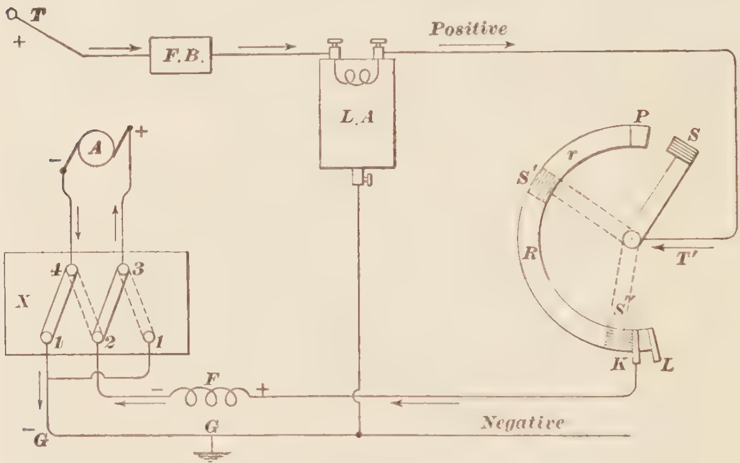


FIG. 8.

it run faster and giving the car greater speed; if the contact shoe is still farther advanced until it reaches the dotted position *S″* and touches the contact plate *K*, all the resistance in *R* is cut out, the path of the current is *T–F B–L A–T′–S″–K–F–2–3–A–4–1* to *G*, and the motor runs at its greatest speed. If the reverse switch *X* is moved over to the dotted position, it is easily seen that the direction of the current through the armature will be reversed, while that in the field will remain the same. The direction of motion will, therefore, be reversed, because it must be remembered that in order to reverse the direction of motion of a motor, either the field or armature may be reversed, but

not both. It would do just as well to reverse the current through the field and leave that through the armature the same, but it is generally the practice to reverse the current in the armature.

13. Shunt Control.—The method of control shown in Fig. 8 is sometimes called **full-field control,** in order to distinguish it from what is known as **shunt control.** In Fig. 8, when the car is running at its highest speed, all the resistance is cut out and all the current flows through the field *F*. If a still higher speed is desired, it can be obtained by weakening the field of the motor. The weaker the field, the faster an armature has to run to generate the counter

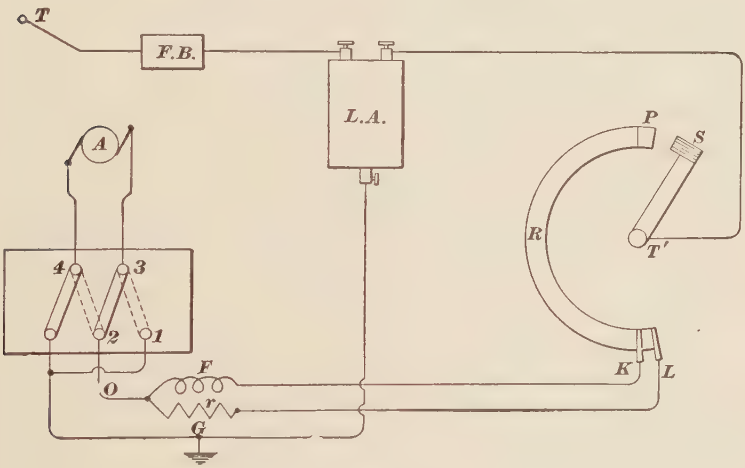


FIG. 9.

E. M. F.; hence, weakening the field increases the speed, but the motor, of course, takes more current. This weakening can be accomplished either by cutting out part of the field turns or by placing a resistance in shunt with the field, thus depriving the field coils of part of the current.

Fig. 9 shows the connections of the shunt method of control as carried out by means of a rheostat. Here a resistance or shunt *r* is connected to one terminal of the field, and the other end is connected to plate *L* on the rheostat.

When the shoe rests on both *K* and *L*, the current, in order to get to point *O*, passes through two paths that are in multiple; path *K–F–O* includes the field and path *L–r–O* includes the shunt. As the shunt generally measures about three times as much as a warm field, it takes away from the field one-fourth the total current. It must be borne in mind that the final result of bringing the shunt into action is to increase the speed of the car, and the car cannot be made to go faster under given conditions without being furnished with more power; this increase in power is provided by the increase in the current due to the weakening of the motor field by the shunt. The use of shunts was at one time quite common, but it is not so generally followed now. The latest equipments are not provided with shunts, because it is found that all the speed control that is necessary can be obtained without them, and their use only leads to complication and opens up chances for trouble.

14. Use of Platform Controller.—The old-style rheostat, Fig. 6, was soon replaced by the platform controller. It was found that the movable arm on the rheostat under the car gave considerable trouble, so the next step was to place the resistance itself under the car and run wires from it and the motors to a controller placed on the platform. The controller is a device for cutting out the resistance or for effecting any combinations necessary for the control of the speed. Many kinds of controllers are made to meet different conditions of service. Fig. 10 shows how the movable arm of the rheostat may be replaced

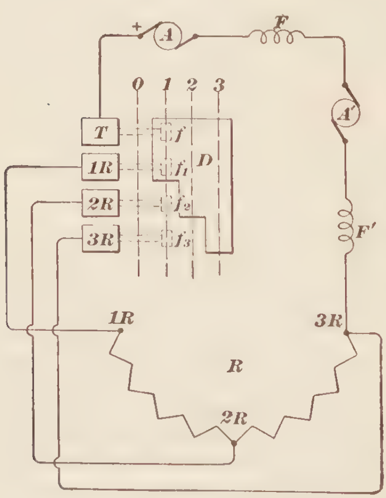


FIG. 10.

by a simple controller and also how the cutting out of resistance is effected. R is a resistance divided into two parts; one part lies between $1\,R$ and $2\,R$ and the other part between $2\,R$ and $3\,R$; F and A are the field and armature, respectively, of a dynamo that is to furnish the current for running the motor whose field and armature are F' and A'; D is a round casting fitted on a wooden drum provided with an iron shaft that turns in bearings. This casting is here shown as straightened out flat, although it is really cylindrical in shape. T, $1\,R$, $2\,R$, and $3\,R$, in the upper part of the figure, are brass finger stands, on each of which is a finger, hanging over D, as indicated by the dotted lines and marked in the figure f, f_1, f_2, f_3. A wire is connected to each of the finger stands. Stand T is connected to the trolley wire; stands $1\,R$, $2\,R$, and $3\,R$ are connected to the resistance coil at points marked with the corresponding letters. On this controller there are four notches, indicated by the dotted lines, marked *0*, *1*, *2*, *3*. The line marked *0* denotes the off-position, and no current can pass through the circuit, because the trolley finger f hangs in the air, as shown in Fig. 11 (a), without touching the contact plate c mounted on the drum D. Dotted line *1* denotes the first notch, and fingers f and f_1 touch the contact plate on drum D, as shown in Fig. 11 (b). The circuit being, therefore, closed, the current can flow through the path A–T–f–D–f_1–$1\,R$–$1\,R$–$2\,R$–$3\,R$–F'–A'–F–A. Dotted line *2* denotes the second notch where the drum is turned until finger f_2 makes contact; the path of the current is then A–T–f–D–f_2–$2\,R$–$2\,R$–$3\,R$–F'–A'–F–A. On the second notch, when the current gets to drum D, it finds two paths by means of which it can reach point $2\,R$ on the resistance coil; one path is f_1–$1\,R$–$1\,R$–$2\,R$, and the other path is f_2–$2\,R$–$2\,R$. The first path has a part of the resistance coil in it and the second path (i. e., car wire $2\,R$–$2\,R$) has very little resistance. Wire $2\,R$–$2\,R$ then short-circuits the $1\,R$–$2\,R$ part of

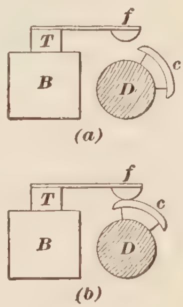


FIG. 11.

the resistance. When the drum is turned another notch, and finger f_3 comes into contact, the path of the current is $A-T-f-D-f_3-3\ R-3\ R-F'-A'-F-A$. Wire $3\ R-3\ R$ short-circuits the whole resistance in R and the motor runs on full field directly across the line, just as it does in Fig. 8, when S touches K. This controller gives a means of cutting out resistance, but the cutting out is not as gradual as where the rheostat arm is used. It is found, however, in practice that three or four resistance notches are sufficient to give a car a smooth start if the controller is handled properly.

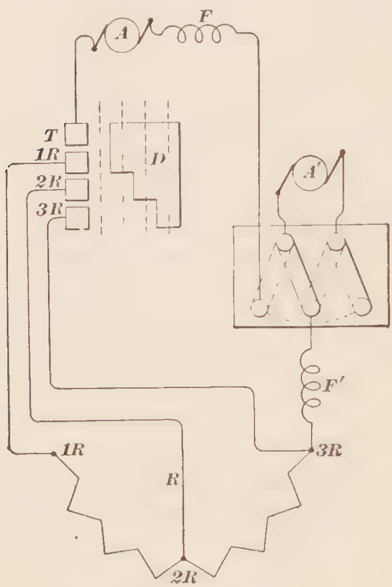


FIG. 12.

15. Fig. 12 shows how an ordinary reversing switch might be used with a simple controller of this kind. However, in modern controllers it is the practice to have the reversing switch also made in the form of a drum and to mount it in the same case with the power drum.

RHEOSTATIC CONTROLLER.

16. General Construction.—Fig. 13 shows a modern type of rheostatic controller designed by the General Electric Company for the control of cars, haulage locomotives, or hoisting motors. This controller is considered somewhat in detail because it contains many of the features found on controllers used on street cars and will serve as a good introduction to the study of them. The controller

shown in Fig. 13 is designed to handle one 50-horsepower 500-volt motor or one 25-horsepower 220-volt motor, i. e., its contacts are large enough to handle about 75 amperes. The figure shows the cover *A* thrown back so as to expose the working parts. This controller is of the *magnetic blow-out type*, and is known as a type R controller because it uses rheostatic control. In the General Electric

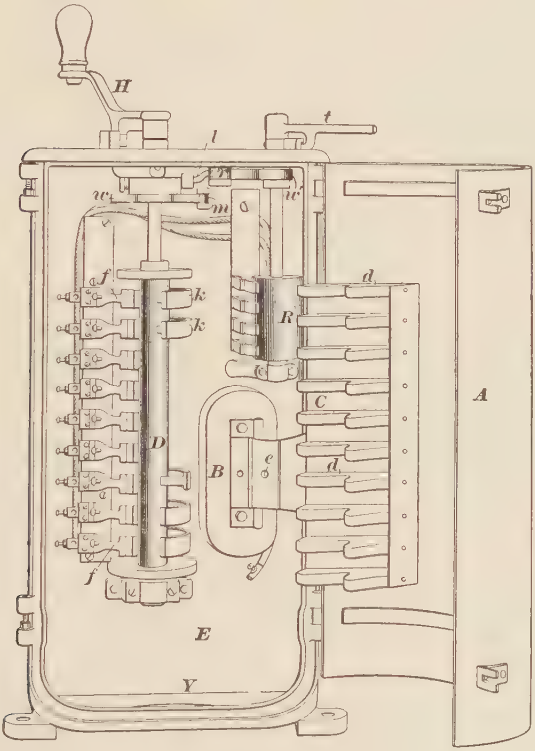


FIG. 13.

Company's controllers, a magnetic field is used to extinguish the arc that would otherwise form at the contact tips and cause blistering and burning. This method of preventing arcing has proved very effective. *B* is the coil that sets up the magnetic field necessary to blow out the arc, and is therefore called the **blow-out coil.** The iron back of the

controller forms one pole piece and the polar extension *C* the other. Pole piece *C* is shown swung back so as to give access to the **power drum** *D*. When the controller is in use, the pole piece *C* is swung over and held in position by a bolt passing through hole *c*. Fig. 14, although not drawn to scale, will give an idea as to the relation of the pole piece *C*, drum *D*, and the controller back *E* when the pole piece is swung into position. The pieces *d* are **arc guards,** and are made of vulcabeston (vulcanized asbestos); they pass between the contact arcs and prevent arcing between the contacts. The whole of the current supplied to the car passes through blow-out coil *B* and sets up a magnetic field between *N* and *S*, as indicated by the curved dotted lines.

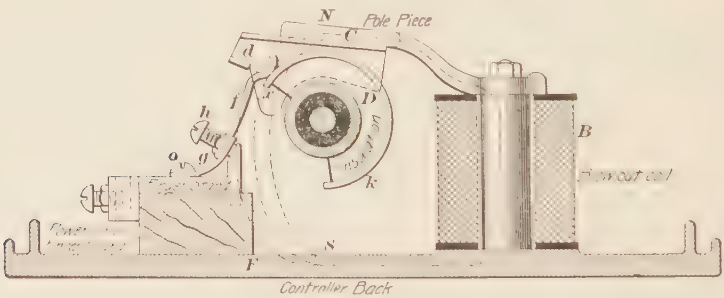


FIG. 14.

When the drum is revolved far enough, the tip *x* of contact arc *k* leaves finger *f* and an arc tends to form. This arc acts in the same way as a flexible wire carrying current, i. e., it is forced across the field just as the conductors on the armature of a motor are forced to move on account of the reaction of the magnetic field set up around the wire on the field supplied by the field magnets. In this case, the arc is forced across the field and stretched out until it is broken. The action is practically instantaneous, so that there is little or no burning of the fingers and contact arcs. The fingers *f* are stamped out of thick copper and are fastened to a flat phosphor-bronze spring *g*, which is in turn fastened to the cast-brass finger stand by means of screws *o*, so that

fingers may be replaced at any time. The screw h is for adjusting the amount that the finger drops when the drum passes from under it. This affects the pressure with which the fingers press on the drum, and they should be adjusted so as to drop about $\frac{1}{32}$ to $\frac{1}{16}$ inch. The contact arc $x\,k$ should frequently be rubbed with a little vaseline so as to prevent wear and cutting.

17. Star Wheel, or Index Wheel.—The power drum is operated by means of the power handle H, Fig. 13, which fits on the top of the power-drum shaft. In order to compel the power drum to take up a definite position corresponding to the various steps, it has a **star wheel, or index wheel,** w attached to the shaft. This engages with a spring-actuated roller m, which is pulled into the various notches on the star wheel and forces the drum into its proper position. It is this star wheel and roller that gives the movement of a controller handle its springy feeling.

18. Reverse Drum.—The reversing switch, or reverse drum, as it is called, is shown at R. This is a much smaller and simpler drum than the power drum, and it is mounted in the upper right-hand corner of the controller. Its sole function is to reverse the armature connections in case it is desired to run the car in the opposite direction. It is not intended to turn the current on or off or effect any changes in the resistance. For this reason, the reverse drum is not provided with any device for suppressing arcing, and its contact fingers are somewhat lighter than those on the power drum.

19. Interlocking Device.—In order to make sure that the reverse switch shall not be moved while the current is on, the controller is provided with an interlocking device, that makes it impossible to move the reverse drum unless the power drum is at the off-position. The reverse drum shaft is provided with a star wheel w' having three notches, corresponding to the off-, ahead-, and back-positions. The lever carrying the roller r that engages this star wheel has

a link l attached to it, which runs across to the hub of the star wheel w. The hub of w has a notch in it that comes opposite the end of l when the power drum D is at the off-position, and when the reverse handle t is moved, the end of link l is forced over into the notch until the roller r passes over the projection on the star wheel w', when l falls back far enough to allow D to be turned. At any position of D other than the off-position, there is no notch opposite the end of l; hence, when an attempt is made to move t, the link l comes up against the hub and the reverse drum is locked.

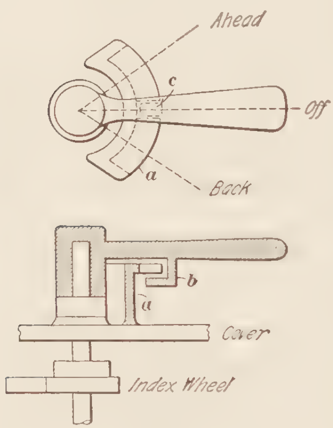


FIG. 15.

When the reverse lever points ahead, the car runs forwards, and when it points back, the car runs backwards.

The reverse handle is also arranged so that it cannot be removed until the power drum is at the off-position. An **L** guard a, Fig. 15, is cast on the controller cap and overhangs a hook b cast on the handle. A notch c is cut in the guard, so that the handle can be lifted off at the off-position and no other.

One of the principal reasons for this interlocking arrangement is to make sure that the motorman will not reverse the motors while the power is on. In time of danger, the first thing the motorman would naturally do would be to reverse or "plug" the motors. If this were done, the counter E. M. F. of the motors, instead of opposing the line E. M. F., would be added to it and would assist the line E. M. F. in forcing an exceedingly large current through the motors, and, to make matters worse, there would be no resistance in series with the motors. The effect would be the same as a very bad short circuit; in all probability the main fuse would be blown, thus leaving the car helpless, so far as reversing the motors is concerned. If the cylinders

interlock, the motorman first has to throw off the power, then throw the reverse switch. When the power is thrown on again, the resistance will be cut into circuit and there will be much less danger of damage being done.

20. Operation of Rheostatic Controller.—The foregoing will give the student an idea as to the mechanical construction of a controller of this type. The controller has

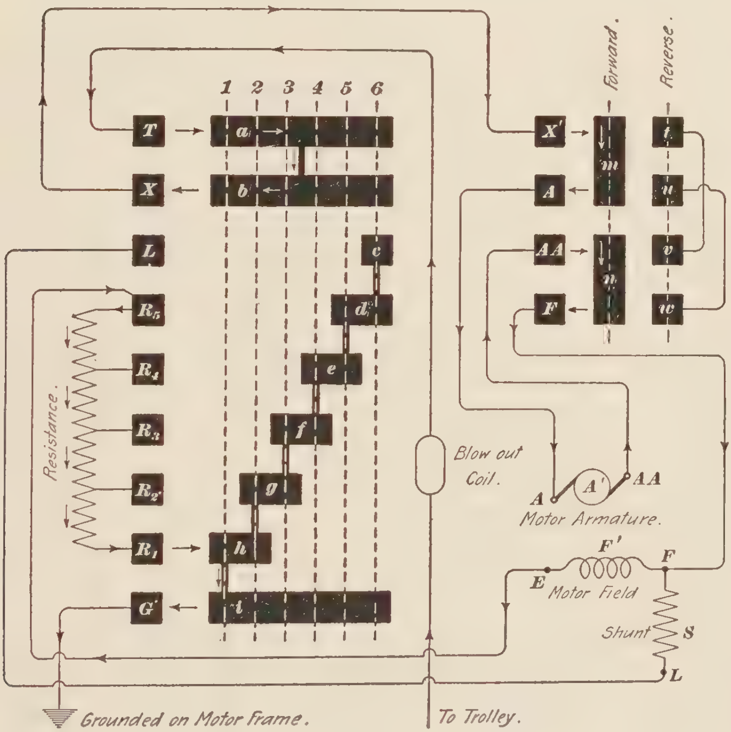
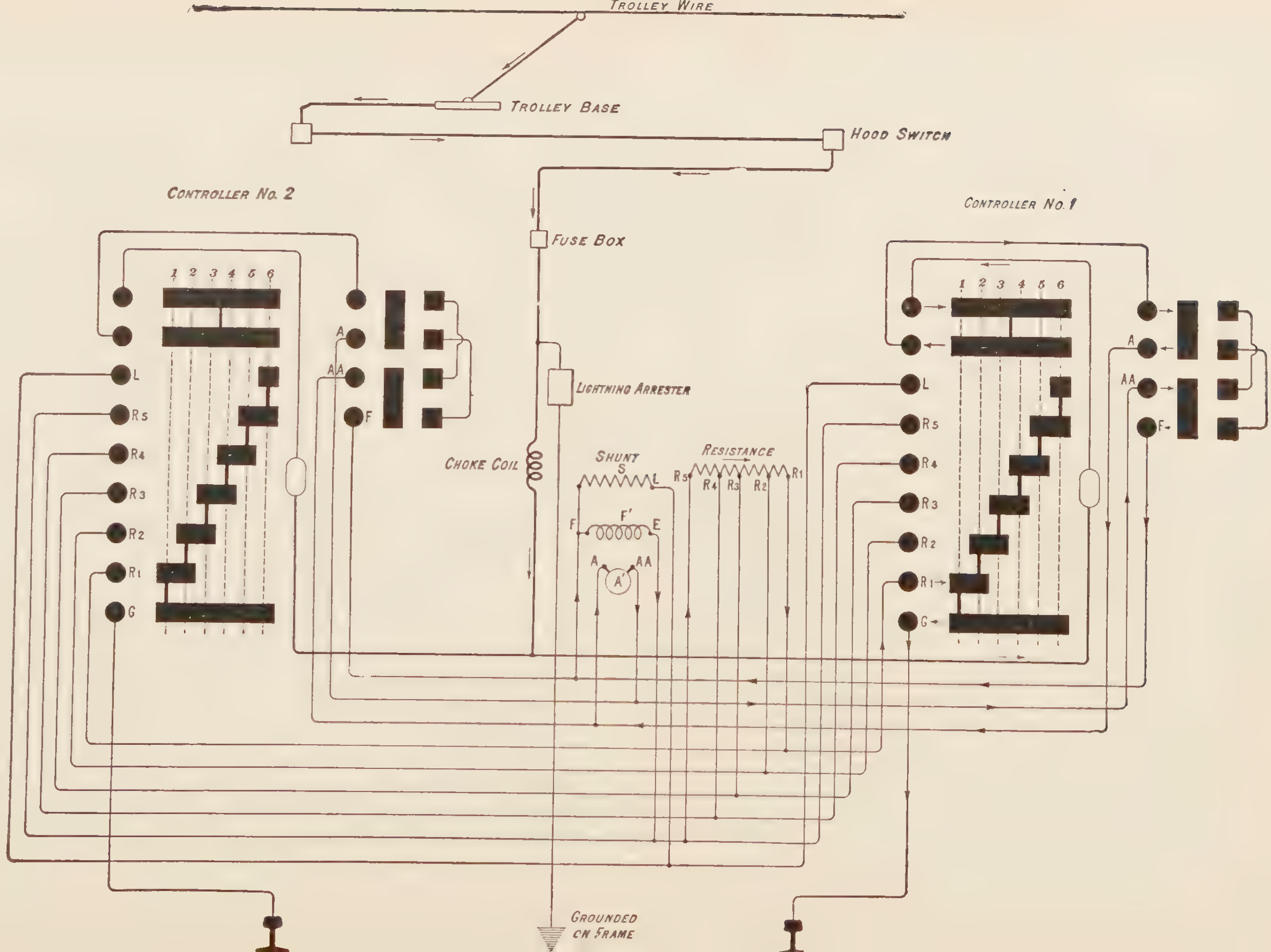


FIG. 16.

six points, and a development of the drum with the various connections is shown in Fig. 16. This diagram shows a single motor, of which A' and F' are the armature and field, respectively. It is operated by a single controller. In this


TROLLEY WIRE
TROLLEY BASE
HOOD SWITCH
CONTROLLER No. 2
CONTROLLER No. 1
FUSE BOX
LIGHTNING ARRESTER
CHOKE COIL
SHUNT
S
RESISTANCE
R5
R4
R3
R2
R1
L
F
F'
E
A
AA
A'
1 2 3 4 5 6
G
GROUNDED ON FRAME

controller figure and in those to follow, the drum contact arcs are indicated by black bands, which represent the arcs straightened or developed out flat. The finger stands on the power drum, and on the reverse drum connection boards are represented by the row of square black spots. The vertical dotted lines represent the various positions of the drum. Note that the drum is in two parts. Contact arcs *a* and *b* are connected together, but these two are insulated from *c*, *d*, *e*, *f*, *g*, *h*, and *i*, which are all connected together, because they constitute a single casting. On the first notch, fingers *T*, *X*, R_1, and *G* make contact with their respective arcs. All the others hang over and touch nothing.

The path of the current on the first notch is indicated by the arrows, and is as follows: Trolley–blow-out coil–*T*–*a*–*b*–*X*–*X'*–*m*–*A*–*A*–armature *A'*–*AA*–*AA*–*n*–*F*–*F*–field *F'*–*E*–R_6–through the whole of the resistance–R_1–*h*–*i*–*G* to ground, thus completing the circuit from the trolley to the rail.

On the second notch, finger R_2 touches arc *g*, and when the current reaches R_6, it flows through three sections only of the resistance, because when it reaches R_2, it takes the path R_2–*g*–*h*–*i*–*G*. On the third notch, the section of resistance between R_2 and R_3 is cut out. On the fourth notch, that between R_3 and R_4, and on the fifth notch all the resistance is cut out, and the path of the current is: trolley–blow-out coil– *T*–*a*–*b*–*X*–*X'*–*m*–*A*–*A*–*A'*–*AA*–*AA*–*n*–*F*–*F*–*F'*–*E*–R_6–*d*–*e*–*f*–*g*–*h*–*i*–*G*. The fifth notch, then, gives the highest speed that can be attained by simply cutting out resistance.

On this controller a shunt *S* may be used and a sixth notch is provided, so that on this notch the shunt will be connected across the motor field coil, thereby weakening the field and increasing the speed. One end of this shunt is attached to *F* and the other end to finger *L*. On the sixth notch, the path of the current is the same as on the fifth notch up to the point *F*; here the current divides, part of it taking the path *F*–*F'*–*E*–R_6–*d*–*e*–*f*–*g*–*h*–*i*–*G*, and the other part the path *F*–*S*–*L*–*L*–*c*–*d*–*e*–*f*–*g*–*h*–*i*–*G*, thus taking part of the current away from the field.

21. Operation of Reverse Switch.—If the motor is to be reversed, the reverse switch is thrown over, bringing contacts t, u, v, w under fingers X', A, AA, and F, respectively. When the current reaches X', it takes the path X'–t–v–AA–AA–A'–A–A–u–w–F. In other words, it flows in at the AA end of the armature instead of at the A end as before, but it still flows in at the F end of the field, thus reversing the current through the armature, but not through the field. The lettering of the various connecting posts in the controller is that used by the General Electric Company.

22. Car With Two Rheostatic Controllers.—In Fig. 16, only one controller is shown, in order to simplify matters, but on a car or mining locomotive two controllers, one on each end, are usually necessary. Fig. 17 shows two of these controllers connected together and operating a single motor with the parts arranged in about the relative positions they would occupy on the car. The corresponding connecting posts of the two controllers are connected together by the long wires that run the length of the car. These wires are sometimes called **hose wires,** because they are usually in the form of stranded copper cables run in canvas hose. In some cases, however, the wires are run separately and fastened to a board by means of cleats. Of course, when one controller is in use, the other is at the off-position, because the handle of the reverse switch cannot be removed until the power is thrown off. The arrowheads show the path of the current when controller No. *1* is on the first notch. This is practically the same as that shown in Fig. 16, except that the parts are in a little different location. Notice that the current passes through both hood switches and the fuse box before reaching the controllers. The wires in this diagram, Fig. 17, are not supposed to touch each other where they cross unless there is a round dot placed at their point of intersection. As an exercise, the student should trace out the path of the current on the other points, in order to become familiar with the method of

representing the car wiring. The various combinations may be represented diagrammatically, as shown in Fig. 18. The first five steps differ from each other in the amount of resistance included, and the last step is the same as the fifth, with the exception that the field F' is shunted.

When a rheostat is used continuously to control the speed, it must be proportioned so as to avoid overheating, and all the resistance notches may be used as running notches.

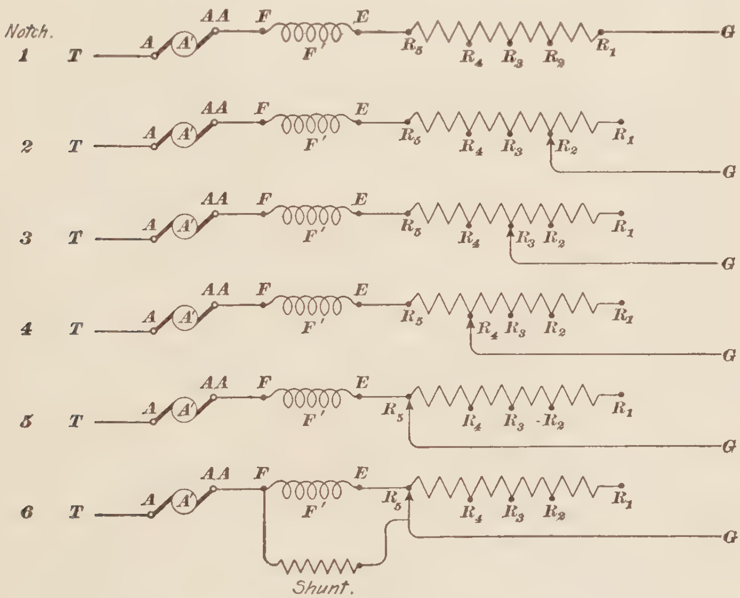


FIG. 18.

With ordinary street cars, however, the resistance is not supposed to be used for speed-controlling purposes. It is only used to give the car a smooth start and should not be used to run on. Before leaving the study of this controller, it may be well to notice that the resistance coils are here placed next to the ground, so that the current first enters the motor. In most controllers the resistance is placed ahead of the motors, but on the whole it makes no difference so far as the effect of the resistance itself goes; it

sometimes does, however, make a difference in regard to the amount of trouble that arises on account of grounds occurring on the resistance. Also notice, in Fig. 17, that the post marked *AA* on controller No. *1* is connected to post *A* on controller No. *2*, and post *AA* on controller No. *2* is connected to post *A* on controller No. *1*. This is done in order that the car may always run forward when the reverse handle on the end from which it is run points ahead.

SERIES-PARALLEL CONTROL.

23. General Description.—The method of speed control now almost universally used for street-railway work is known as the **series-parallel** method. It enables the voltage applied to the motors to be cut down for slow-speed running without the use of resistance, and hence is more economical on low speeds than the rheostatic method. At least two motors per car are required. For slow speed, these motors are connected in series, and for high speed, they are connected in parallel; hence, the name series-parallel applied to this system of control.

Since the motors are designed to operate normally on 500 volts—that is, when supplied with this pressure across their terminals they will run at their maximum speed—let us assume that the pressure furnished is 500 volts. Then, if the two motors on a car are connected in series, as shown in Fig. 19, it is evident that the pressure across each motor will be only 250 volts. Each motor will then have to run at only about half its normal speed to generate the required counter E. M. F., and the result is that a slow speed is obtained without the use of any resistance.

When the higher speed is desired, the controller is thrown around to the "multiple notches" and effects the combinations necessary to change the motors from series to parallel. When they are in parallel, as shown in Fig. 20, each motor gets its full voltage of 500 and runs at full speed. Of course, at starting it is necessary to include some

resistance, and when changing from series to multiple, resistance is also cut in to prevent excessive rushes of current and to give a smooth acceleration to the car; but this resistance is cut out as soon as the car gets under headway and is not to be used on the running notches.

A great many types of series-parallel controller have been brought out, and it would be an endless task to describe all

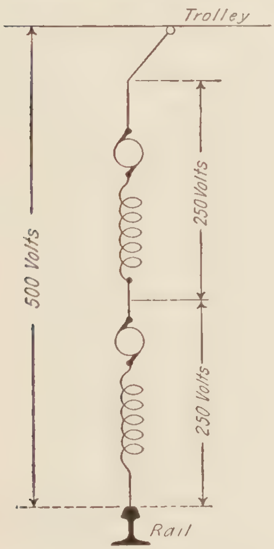


FIG. 19.

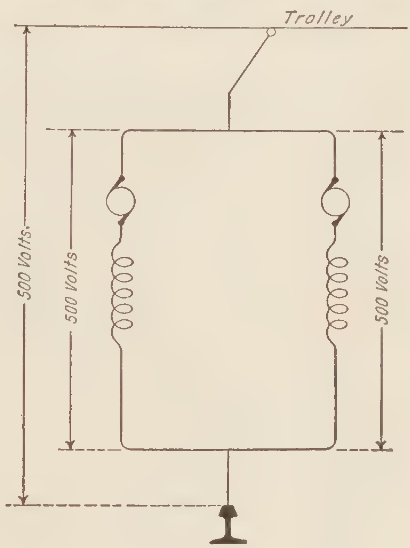


FIG. 20.

of them. All that is necessary here is to show their principles of operation, because if the student understands these thoroughly, he should have little difficulty in tracing out any ordinary car-wiring diagram. The diagrams of car wiring are usually furnished by the controller makers to those that use their apparatus.

K2 SERIES-PARALLEL CONTROLLER.

24. General Description.—The type K2 series-parallel controller brought out by the General Electric Company is one that has been very widely used on electric railways.

The General Electric Company make several styles of what they designate as the type K controller. They are, however, the same in general construction and principles of operation. In all the type K controllers one of the motors is shunted or short-circuited during the change from series to parallel, otherwise the designation "type K" has no special significance. The type K controllers embody many of the features already described in connection with the type R controller. The magnetic blow-out is arranged in the same way, and the general mechanical construction is the same, though, of course, the type K is more complicated, because it must handle all the connections for two motors and effect the changes necessary to throw the motors from the series to the parallel arrangements. It is also provided with switches, by means of which either of the motors may be cut out, in case one of them becomes disabled, allowing the car to be operated on the other motor. The K2 controller is designed for use with shunts, i. e., on the last series notch the fields of both motors are shunted and the same is also the case on the last multiple notch.

FIG. 21.

The K2 controller is used on motors of 35 horsepower or under and has nine notches. There are more positions than this, but only nine of them are marked on the controller top, and the mechanism of the controller is so fixed that the handle cannot be easily made to rest anywhere except on a marked notch. This is done so that the drum will not hang between notches and cause burning inside the controller. Fig. 21 shows the K2 controller with the door closed, as it appears on the end of a car; Fig. 22 shows the door opened so that the inside parts may be seen.

In Fig. 22, *1* is the controller handle that turns the controller or power drum *2*; *3* is the reverse handle that turns

the reverse drum *4*; *9*, *9* are the fingers or wipers that make contact with the power drum; *6* is the blow-out magnet. The reverse drum and its fingers have no blow-out coil.

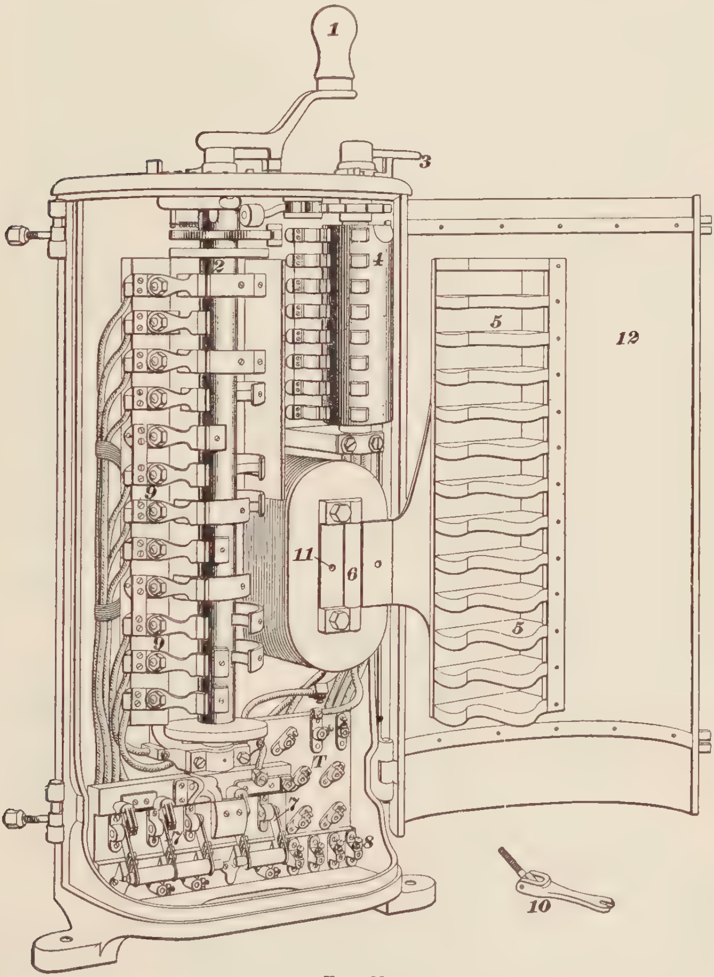


FIG. 22.

because the reverse drum cannot be moved while the current is on, and there is, therefore, no arc there to be put out. *7*, *7* are the **cut-out switches,** by means of which a disabled

motor may be cut out; *8* (in the lower right-hand corner) is the **connection board,** into which all wires run from the motors and other devices, as well as the ground and trolley wires. The terminals on the connecting board also connect to the various parts of the controller, as will be shown later

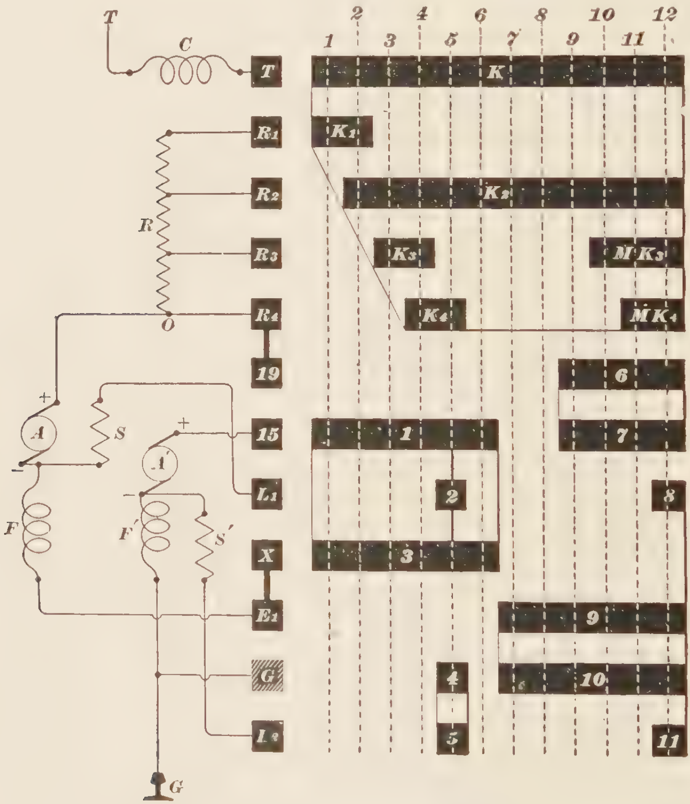


Fig. 23.

in another diagram. *12* is the door, or cover, that swings back as shown, and *10* is the bolt and wrench used for holding the pole piece in place when it is swung over; *5*, *5* are the arc guards, mounted in the way previously described. It will be noticed that both the power drum and the reverse

drum of this controller are longer than those of the rheostatic controller. The interlocking device between the two drums is practically the same on both, but the connection board *8* is made necessary on account of the numerous connections and the addition of two cut-out switches *7*, *7*.

25. Fig. 23 shows the K2 controller with the power drum fully laid out, but the reverse switch, the motor cut-outs, and the controller connections are omitted for the present, in order to simplify matters. The letters used on the controller fingers are the same as those used on an actual controller. T is the trolley finger; R_1, R_2, R_3, R_4 are the resistance fingers. F and A are the field and armature of the No. 1 motor; F' and A' are the field and armature of the No. 2 motor; S is the No. 1 shunt and S' the No. 2 shunt. E_1 is the free end of the No. 1 motor field, and the free end of No. 2 motor field is grounded. L_1 is the free end of the No. 1 shunt S around the field F of the No. 1 motor, the other end being spliced to one end of the No. 1 motor field. L_2 is the free end of the No. 2 shunt, the other end being spliced to one end of the No. 2 motor field. G is the ground finger; *15* and *19* are fingers that ordinarily take wires running from the reverse switch, but as the reverse switch is left out, the wires are in this case run direct. There are twelve positions, as indicated by the twelve vertical dotted lines, but there are only nine notches. Three of the positions the motorman knows nothing about, further than that he can feel a change take place when the controller handle is swept over these positions in going from series to parallel.

26. The **first position** is the first notch; the two motors are in series and the whole of the starting coil is in the circuit. The **second position** is the second notch; the two motors are in series and part of the starting coil is cut out. The **third position** is the third notch; the motors are still in series, but more of the starting coil is cut out. The **fourth position** is the fourth notch. The motors are still in series, but the whole of the starting coil is cut out. The

upper part of the drum simply looks after the cutting out of the resistance. The lower drum segments (those numbered) look after the changing from series to parallel and the cutting in of the shunts S and S'. The path of the current on the fourth notch is $T–C–T–K–K_4–R_4–A–F–E_1–X–3–1–15–A'–F'–G$.

The **fifth position** is the fifth notch. The motors are in series, all the starting coil is cut out and each field has a shunt in multiple with it. As soon as the fifth notch is reached, three drum plates *2*, *4*, and *5* and three new fingers L_1, G, and L_2 are brought into action. It must be borne in mind that one end of S is spliced to one end of F and one end of S' is spliced to one end of F'. As soon as L_1 touches plate *2*, the free end of S makes contact, through $L_1–2–3–X–E_1$, with the negative end of F, and as soon as L_2 and G touch plates *5* and *4*, the free end of S' and the grounded end of F' are brought together, with the result that when the current reaches point $A-$, it splits and gets to finger *15* through two paths: $A--S–L_1–2–1–15$ and $A--F–E_1–X–3–1–15$. When the current gets to point $A'-$, it reaches the ground in two ways: $A'--S'–L_2–5–4–G$ and $A'--F'–G$. The general path of the current on the fifth position, then, is $T–C–T–K_4–R_4–A–\left\{\begin{matrix} F–E_1–X–3–1–15 \\ S–L_1–2–1–15 \end{matrix}\right\}–$ $A'–\left\{\begin{matrix} F'–G \\ S'–L_2–5–4–G \end{matrix}\right\}$ and to the rail.

27. The **sixth position** is not a notch, but is one of the series of combinations used in passing from series to parallel. It must be noticed that the K2 drum plate, Fig. 23, runs nearly across the drum and that none of the other series-position drum plates touch their respective fingers after the fifth notch is passed. The effect of this is to cut resistance into the circuit again as soon as the drum leaves the fifth position, with the result that the sixth position is the same as the second; i. e., the two motors are in series, have full fields, and that part of the starting coil that lies between R_2 and R_4 is in the circuit. The path of the current,

then, on the sixth position is $T–C–T–K–K_2–R_2$, through the two lower sections of the resistance coil R, and through $A–F–E_1–X–3–1–15–A'–F'–G$. There is no mark on the controller top to show where the sixth position is.

28. The **seventh position** is one of transition, and is not a notch. As the drum leaves the sixth position and goes to the seventh, plates *3* and *1* pass out of service and plates *9* and *10* pass into service; the effect of plates *3* and *1* going out of action is to drop the No. 2 motor out of the circuit entirely, because the field end of the motor goes to the ground and the $A'+$ end of the motor goes to finger *15*, which hangs in the air as soon as plate *1* passes from under it, and the motor can get no current. But the coming into action of plates *9* and *10* gives the current a new path in place of the one that was broken. The path of the current on the seventh position is $T–C–T–K–K_2–R_2–R–A–F–E_1–9–10$ to the rail G. On the seventh position, then, one motor has been dropped out of the circuit and the car runs on the No. 1 motor in series with two sections of the starting coil. Just at the instant that the fingers are midway in their passage from the sixth position, finger E_1 touches plate *9* at the same time that finger X, to which E_1 is connected, touches plate *3*, with the result that No. 2 motor is momentarily short-circuited, through $A'+–15–1–3–X–E_1–9–10–G–F'–A'–$, just before it is cut out of circuit; but this cannot be felt, because there is so much of the starting coil in ahead of both of the motors.

29. The **eighth position** is the same as the seventh position, and it is not a notch. No new plates are cut into action and no old ones are dropped. The eighth position is a useful one, however, in that it gives the drum a greater distance to travel in its passage from the series to the multiple positions.

30. The **ninth position** is the sixth notch. The two motors are in multiple, have full fields, and are in series with two sections of the starting coil. The arrival of the

drum on the ninth position brings plates *6* and *7* into action, and enables the No. 2 motor to get current through finger *15*. The current divides between the two motors at the point *O* where the resistance wire splices on to the *A*+ armature wire; from there to the ground are two paths; one of them is O–A–F–E_1–*9*–*10*–G and the other path is O–R_4–*19*–*6*–*7*–*15*–A'–F'–G. The ninth position is a marked notch, but is not a running notch.

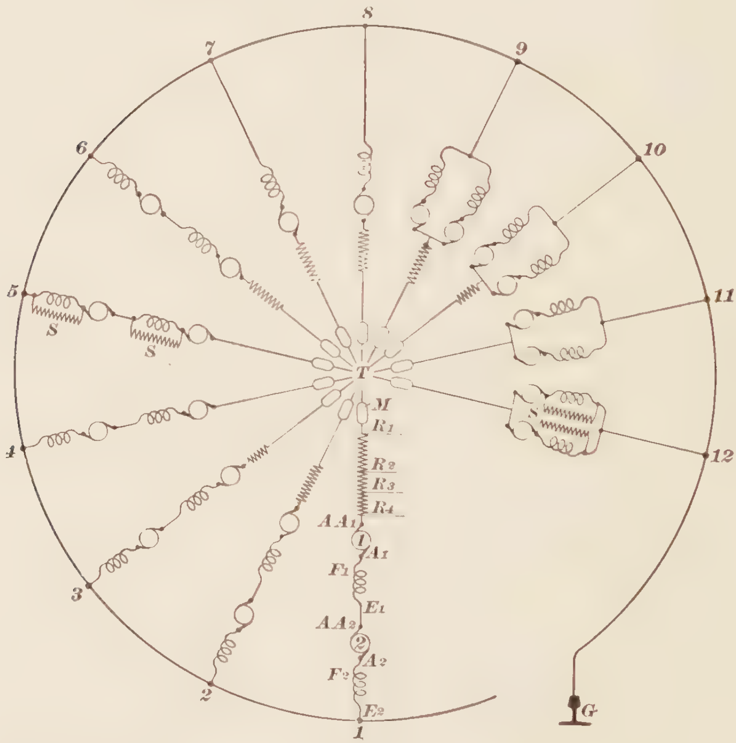


FIG. 24.

31. The **tenth position** is the seventh notch, but it is not a running notch. The two motors are in multiple and are in series with but one section of the starting coil, because finger R_3 touching plate MK_3 cuts out that part of the coil that lies between R_2 and R_3.

32. The **eleventh position** is the eighth notch and is a running notch. The motors are in multiple, have their full fields, and all the starting coil is cut out of the circuit.

33. The **twelfth position** is the ninth notch, which is also a running notch. The ninth notch is the same as the eighth notch, excepting that plates *8* and *11* coming into action put shunts on both the motor fields. The combinations at the various positions are indicated by the diagrams in Fig. 24.

34. The Notches.—On the top of every controller will be found some small ribs, which, in conjunction with the pointer carried on the power-drum shaft, enable the motorman to tell when the drum is on a notch. On controllers of some makes, this pointer is cast on the handle itself, but this is not a good plan, because as soon as the fit between the handle and the shaft becomes loose, the pointer indicates wrongly. Beside the ribs or dashes on the top is usually found the word "off," to indicate the off-position of the drum.

35. Some of the ribs on top of a controller are long and some of them are short. The long ribs indicate the notches on which it is safe to run any length of time; the short ribs

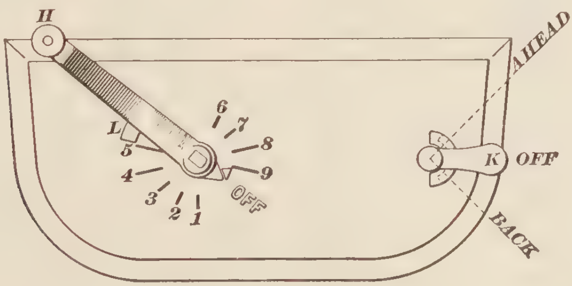


FIG. 25.

indicate the notches to be used only in starting and in going from series to parallel. On the K2 controller there are four of these long ribs; two of them are for the series combination and two for the multiple. The two long ribs in series

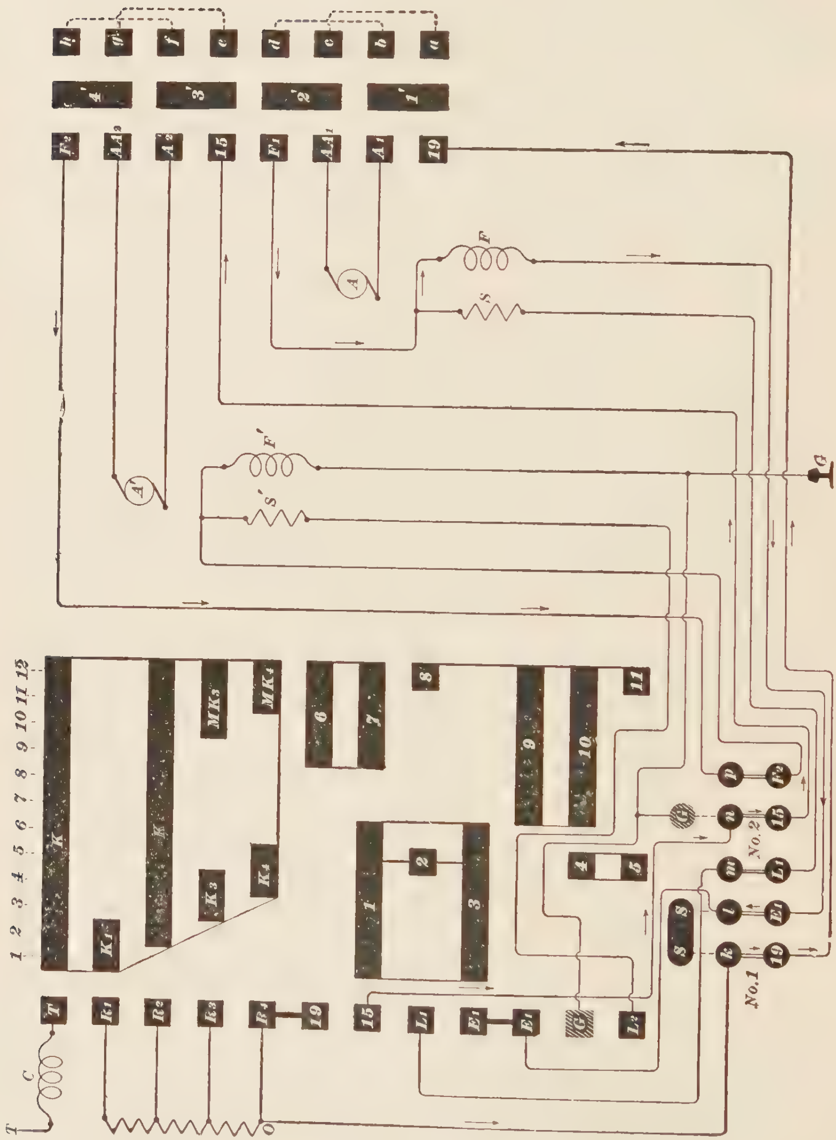


FIG. 28.

indicate the fourth and fifth notches; those in multiple indicate the eighth and ninth notches. The K2 controller has, then, four running notches: the fourth, fifth, eighth, and ninth, and none of the other notches should be run on for any length of time, for it is a waste of power and an abuse of the starting coil.

36. Fig. 25 shows the layout of the K2 controller top. *H* is the power-drum handle resting on the off-position; *K* is the reverse handle, also at the off-position. If *K* is moved ahead, the car will move ahead as soon as *H* is moved until its pointer points to *1*; if *K* is moved back, the car will move backwards. *L* is a lug against which a projection on the handle bears when the handle is moved to the ninth notch or to the off-position. On old-time types of controllers, it was necessary to watch the pointer very carefully to avoid running in between the notches, thereby burning the controller tips and fingers, but on modern controllers, the roller that plays into the notches on the drum index is acted on by a spring that is strong enough to force the drum around as soon as the roller begins to descend into a notch.

37. Reverse Drum.—The reverse drum of the K2 controller is similar in construction to that used on the R controller, except that it is provided with twice as many contact plates and fingers, in order to accommodate the two motors. This switch is shown in the upper right-hand corner of Fig. 26. When the car runs "ahead," the fingers of the reverse switch rest on plates *1'*, *2'*, *3'*, *4'*; when it runs "back," they rest on *a*, *b*, *c*, etc., thus reversing the current through the armatures *A* and *A'*, as previously explained.

38. Motor Cut-Out Switches.—In the lower part of the K2 controller, just below the power drum, the two motor cut-out switches are located. These are seen at 7, 7, Fig. 22, and are marked No. *1* and No. *2* in Fig. 26. This figure shows the controller complete, with the exception of the connection board. As mentioned before, the two motor cut-out switches are used to run the car on one motor if the

other motor or any part of its circuit gives out. These two switches may be thrown up or down, and when the car is in good shape and both motors in use, both switches should be down. Inside the door of every K2, K10, or K11 controller is found a card that tells how to cut out a faulty motor; one motor is called the No. 1 motor and the other the No. 2 motor; the No. 1 motor is the motor on the fuse-box end of the car. Inside the No. 1 controller, the card reads: "*To cut out motor No. 1* (*the motor nearest this end of car*), *throw up left-hand switch as far as it will go. To cut out motor No. 2* (*motor nearest other end of car*), *throw up right-hand switch as far as it will go.*" Inside the No. 2 controller, the card reads: "*To cut out motor No. 1* (*motor nearest other end of car*), *throw up left-hand switch as far as it will go. To cut out motor No. 2* (*motor nearest this end of car*), *throw up right-hand switch as far as it will go.*" The motor cut-out instruction cards read differently on the two ends of the car, because on the front end the No. 1 motor is the front motor and the No. 2 motor is the rear motor; but on the rear end the No. 2 motor is the front motor and the No. 1 motor the rear motor.

39. The shaft of the power drum has on it a stop that is interfered with by a pin operated by the cut-out switch in such a way that when either switch is thrown up, the power drum cannot be moved past the fifth notch. If this were not done, the result would be simply to drop the motor out of circuit when leaving the sixth position and pick it up again on the ninth position if the good motor happened to be the No. 1 motor. If the good motor happened to be the No. 2 motor, as soon as fingers E_1 and G made contact with plates *9* and *10*, Fig. 26, there would be a dead short circuit across the line. The way in which this occurs will be shown later.

40. In Fig. 26, the blades of switch No. *1* are hinged to posts k, l, and m; those of switch No. *2* are hinged to n and p. When switch No. *1* is thrown up, posts k and l are connected

by the strip $S S$, and post m is dead-ended because the blade attached to it simply overhangs. When switch No. *2* is thrown up, post n is connected with the ground post G and post p is dead-ended.

41. In Fig. 26, both switches are thrown down, so that both motors are cut in and the path of the current on the first notch is $T–C–T–K–K_1–R_1–O–k–19–19–1'–A_1–A–AA_1–2'–F_1–F–E_1–l–E_1–E_1–3–1–15–n–15–15–3'–A_2–A'–AA_2–4'–F_2–p–F_2–F'–G$. If the No. *1* switch is thrown up to the dotted position, the No. 1 motor is cut out and the path of the current is $T–C–T–K–K_1–R_1–O–k–SS–l–E_1–E_1–3–1–15–n–15–15–3'–A_2–A'–AA_2–4'–F_2–p–F_2–F'–G$. If the No. *2* switch is thrown up to the dotted position (No. *1* switch being down), the No. 2 motor is cut out and the path of the current becomes $T–C–T–K–K_1–R_1–O–k–19–19–1'–A_1–A–AA_1–2'–F_1–F–E.–l–E_1–E_1–3–1–15–n–G–G$.

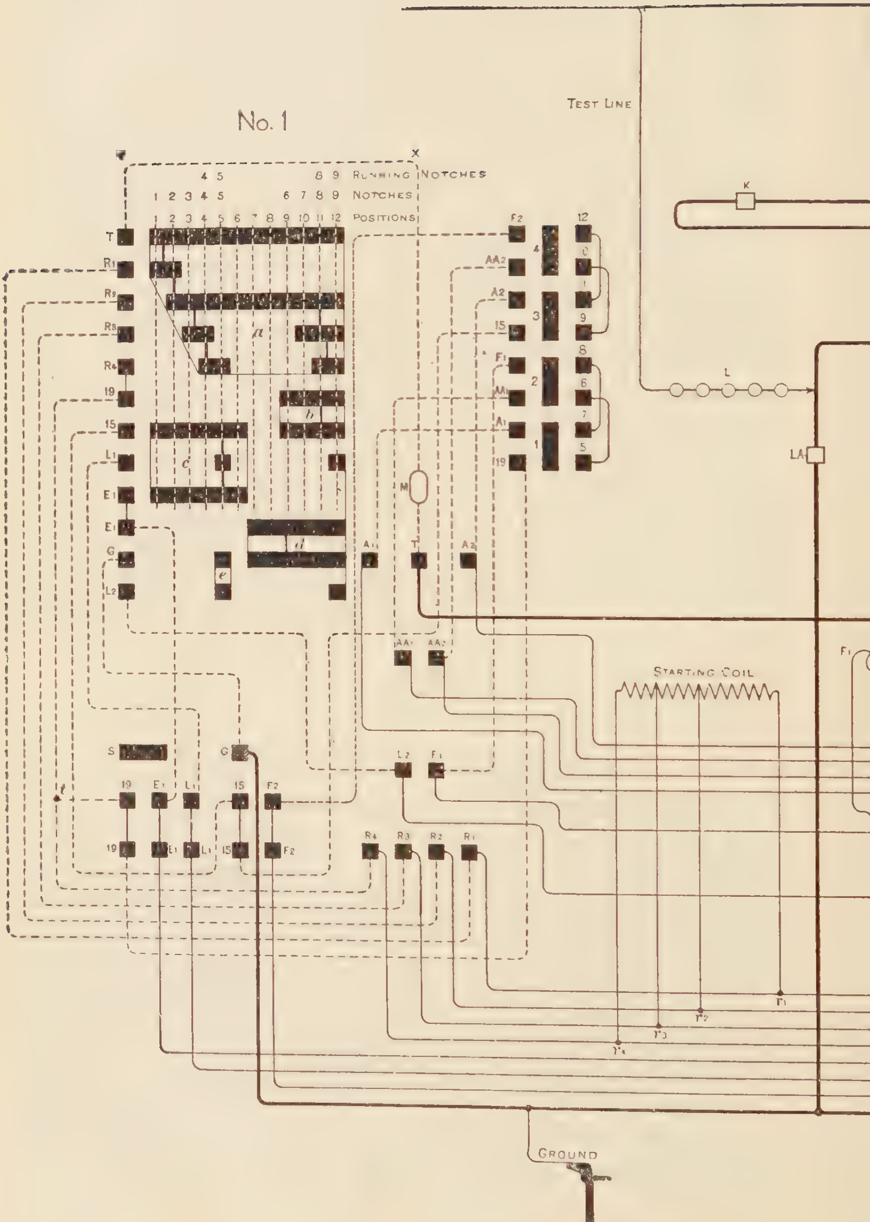
42. If by any chance both switches should be thrown up, thereby cutting out both motors, the path of the current would be $T–C–T–K–K_1–R_1–O–k–SS–l–E_1–E_1–3–1–15–n–G–G$. The resistance coil alone would be in circuit, the car could not start, and any advance of the power handle would cause the main-motor fuse to blow unless some part of the controller should blow first. Such an act as cutting out both motors at the same time is an unusual one, but still it has happened with bad results. It must be clearly understood that a cut-out switch should be used only when the power is off. The switch is not built to break any arc, and any attempt to make it do so is apt to result in not only the destruction of the switch itself, but in injury to the operator's eyes.

The cut-out switches on controllers made by different companies vary somewhat in detail and appearance, but they all drop the motor out of the circuit entirely and put a metal path in its place, so that the current has a bridge over which it can cross in order to reach the motor that is not to be cut out.

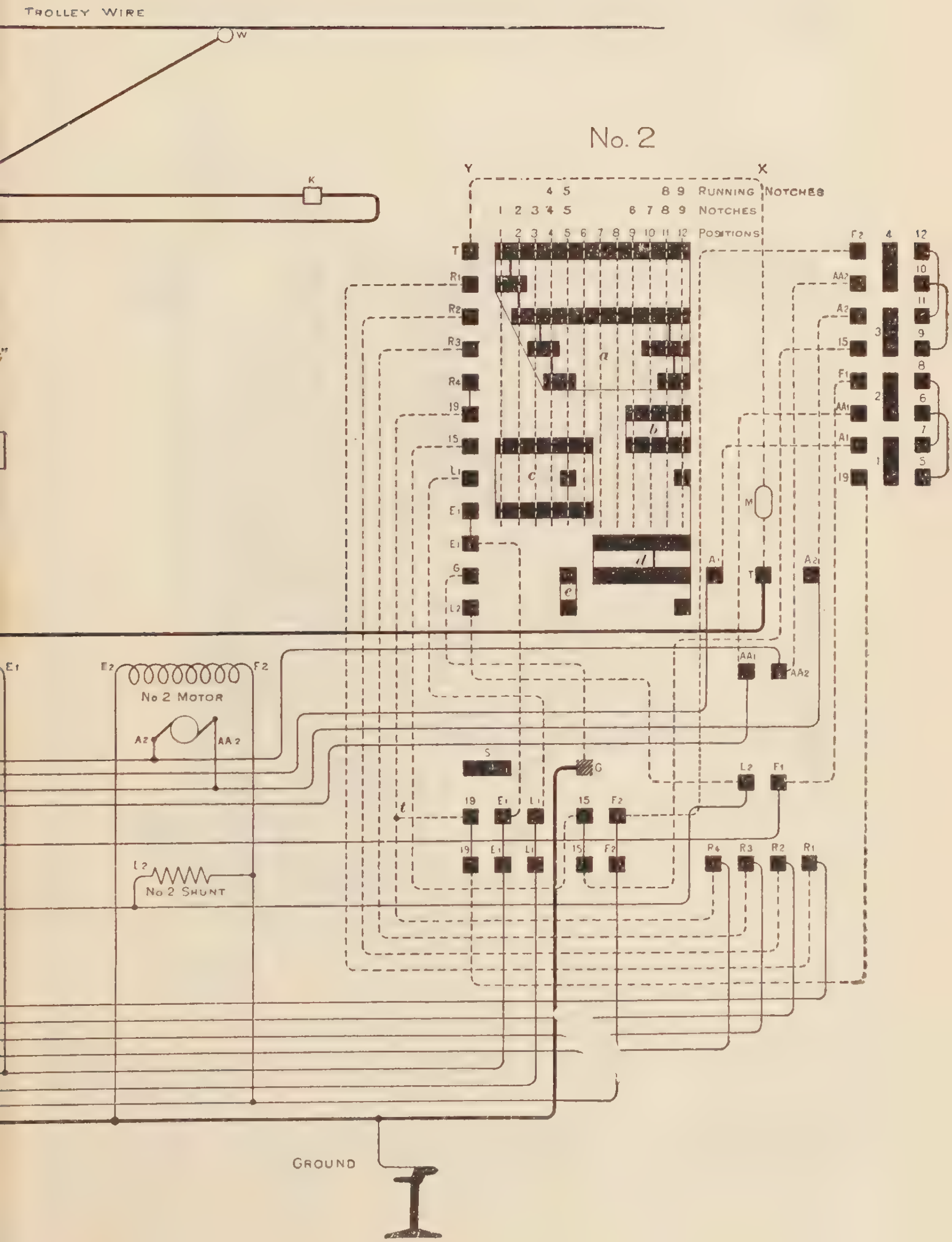
43. Car-Wiring Diagram for K2 Controllers.—Fig. 27 shows a complete car-wiring diagram for two K2 controllers. W is the trolley wheel, K, K the hood switches, $F\,B$ the fuse box, $L\,A$ the lightning arrester. When the No. 1 controller is on the first notch, the path of the current is: W–K–K–FB–choke coil–O–T–M–T–R_1–R_1–r_1 through all the resistance –r_4–R_4–t–19–19–19–1–A_1–A_1–A_1–AA_1–AA_1–AA_1–2–F_1–F_1–F_1–E_1–E_1–E_1–E_1–E_1–c–15–15–15–15–3–A_2–A_2–A_2–AA_2–AA_2–AA_2–4–F_2–F_2–F_2–F_2–E_2–G. The end E_2 of the No. 2 field is permanently connected to the ground wire. The student should, as an exercise, trace out the paths of the current on the other notches, which are indicated by the dotted vertical lines. The fourth and fifth and the eighth and ninth are the running notches. On the fifth and ninth notches the fields are shunted. In Fig. 27, the wire marked "test line" has nothing to do with the regular controller connections. It simply illustrates a method of locating breaks in the car wiring by using a number of lamps L. One end of the test line is connected to the trolley and the free end is touched to the various devices in succession so that the lamps will indicate when the break has been passed.

K11 SERIES-PARALLEL CONTROLLER.

44. Fig. 28 shows the appearance of the K11 controller. This controller is a great deal like the K2, but has two distinguishing features. Its contacts are of larger current capacity, the controller being designed for use with 50-horsepower motors, whereas the K2 controller is intended for use with 35-horsepower motors. The K11 controller is also intended to be used with motors that do not require a shunt, and it is provided with one more resistance notch than the K2. The K2 controller uses a three-part resistance, whereas the K11 resistance has four parts. The K2 controller can handle motors with or without the shunt, the shunt wires being simply left out where no shunts are used, but on



No. 1
Running Notches
Notches
Positions
Test Line
Starting Coil
Ground


Trolley Wire
W
K
No. 2
Y
X
4 5 8 9 Running Notches
1 2 3 4 5 6 7 8 9 Notches
1 2 3 4 5 6 7 8 9 10 11 12 Positions
T
R1
R2
R3
R4
19
15
L1
E1
G
L2
a
b
c
d
e
M
F2
AA2
A2
F1
AA1
A1
A2
AA1
AA2
L2
E1
E2
No 2 Motor
AA 2
No 2 Shunt
S
t
Ground

27.

the K11 controller there are no shunt fingers or connecting-board blocks provided, so that a shunt cannot be used unless

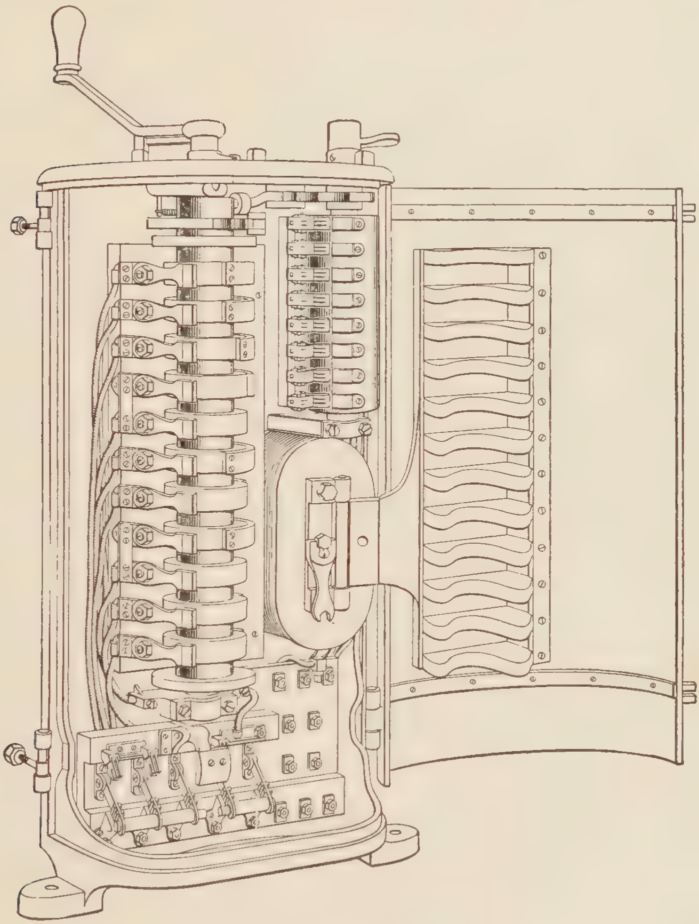
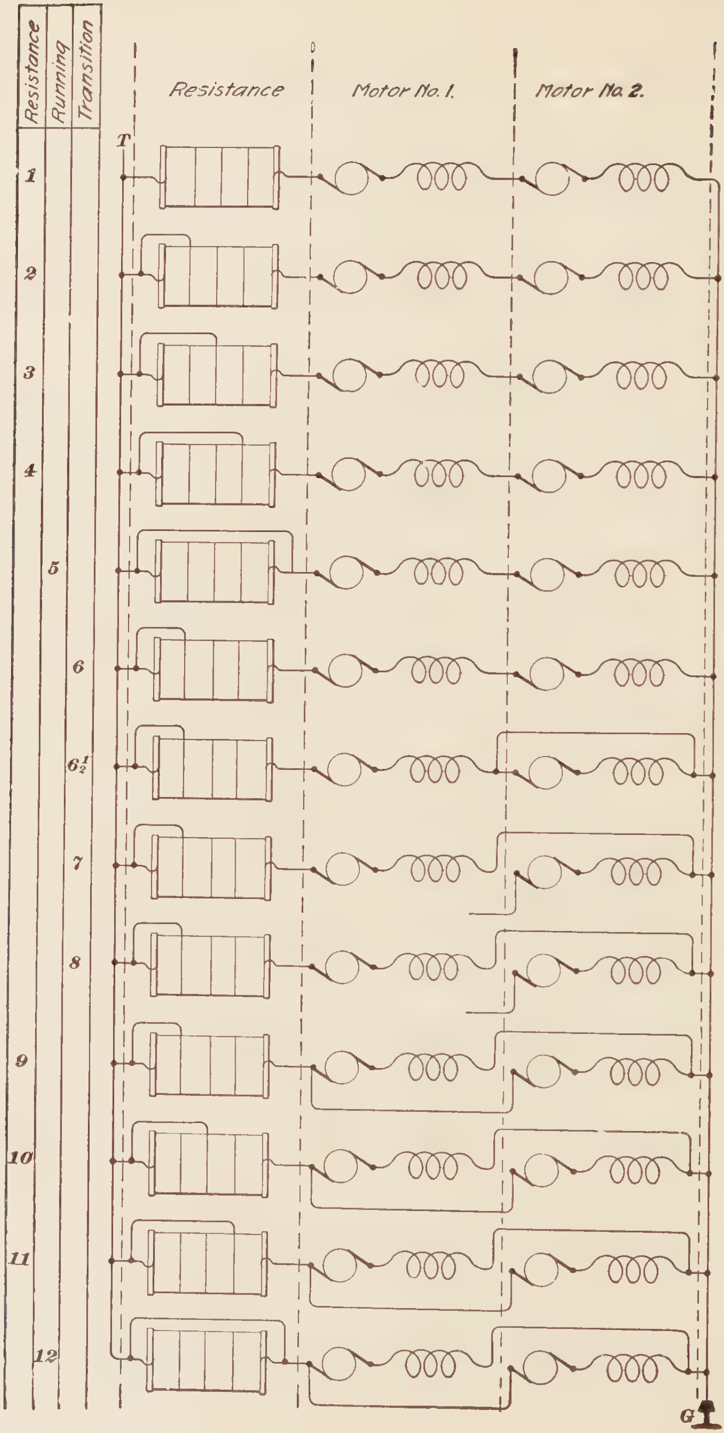


FIG. 28.

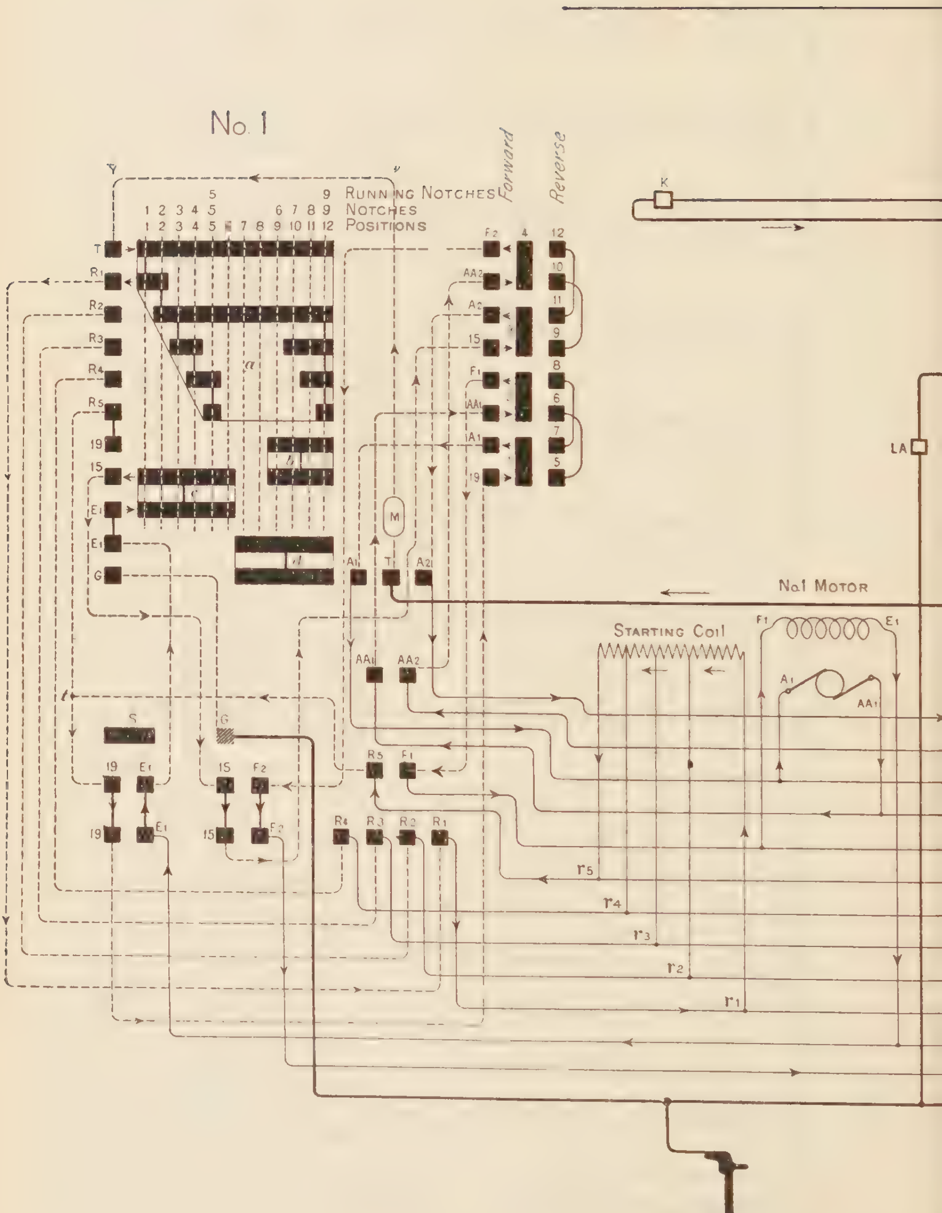
both ends of it are permanently spliced to the two field terminals.

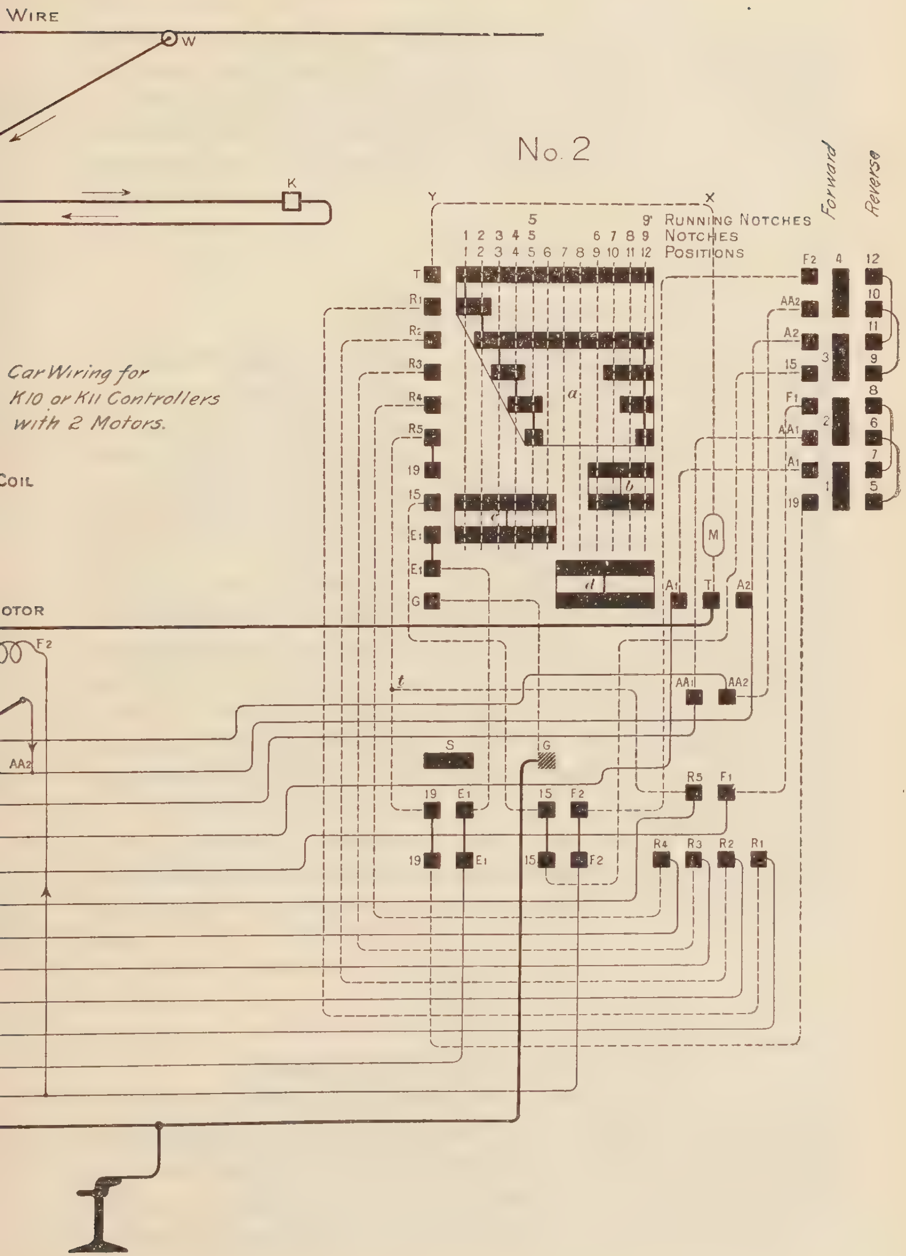
45. Fig. 29 gives the combinations effected on all positions of the power drum. There are five notches in series



Resistance
Running
Transition
Resistance
Motor No. 1.
Motor No. 2.
T
1
2
3
4
5
6
6½
7
8
9
10
11
12
G

FIG. 29.


No. 1
RUNNING NOTCHES
NOTCHES
POSITIONS
Forward
Reverse
No. 1 MOTOR
STARTING COIL
LA
K
M
S
G



WIRE
W
K
No. 2
Forward
Reverse
Y
X
RUNNING NOTCHES
NOTCHES
POSITIONS
Car Wiring for
K10 or K11 Controllers
with 2 Motors.
COIL
OTOR
F2
AA2
a
b
c
d
M
S
G
t

and four notches in multiple, making a total of nine notches, the same as on the K2 controller. But where the K2 controller has four running notches, two in series and two in multiple, the K11 has only two running notches, one in series and one in multiple. These two running notches are the fifth and ninth.

K10 CONTROLLER.

46. The K10 controller is practically the same in appearance as the K2 and is designed for the same class of work. It has replaced the K2 largely, because shunts are not now used as much as they once were, and the K10 is designed for use without shunts. In fact, it makes the same combinations as the K11, so that Fig. 29 may be taken to represent the various steps. It is a lighter controller than the K11 and is used with 35-horsepower motors. It has four resistance sections, and therefore gives the car a somewhat smoother acceleration than the K2. Fig. 30 shows the car-wiring diagram for two K10 controllers. By comparing with Fig. 27, the student will see that the diagrams are very similar. There is one more section in the starting coil and the shunts are omitted, thus simplifying the controller and its connections to a considerable extent. The running notches are the fifth and ninth. On the fifth notch the motors are in series and all the resistance is cut out and on the ninth they are in parallel and all the resistance is cut out.

WESTINGHOUSE 28A CONTROLLER.

47. The Westinghouse Company has manufactured several types of series-parallel controller that differ considerably in detail from those just described. They now supply controllers of the General Electric type, but quite a large number of their older styles are still in use. We will describe the

28A controller. Fig. 31 shows the Westinghouse No. 38 controller, which is very similar in appearance to the 28A. The different sections of the power drum are separated from each other by vulcabeston insulating rings *U*, *U*, *U*, etc., as

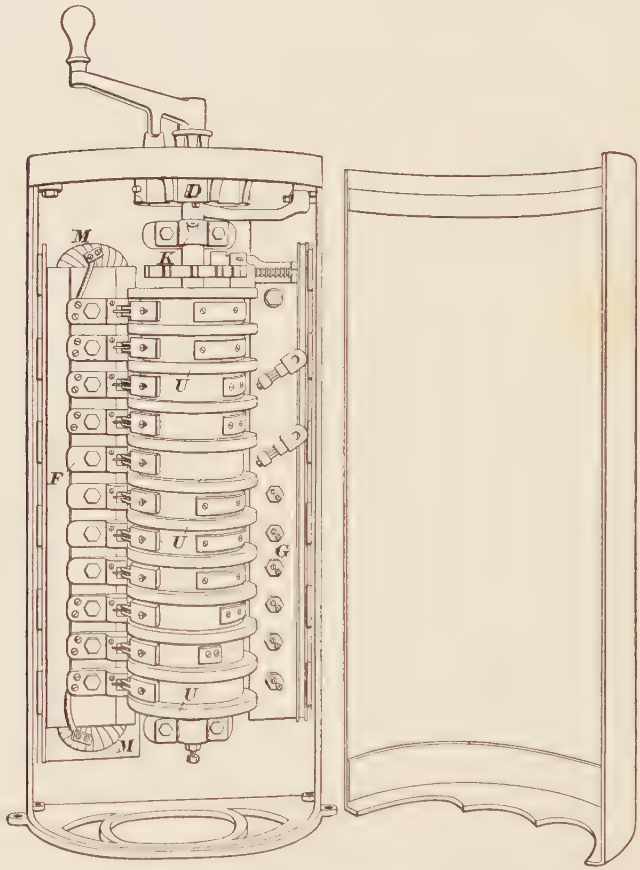


FIG. 31.

shown in Fig. 31. The reverse device, shown at *D*, is of the disk form instead of the drum type, as in the General Electric Company's type K2. The power-drum finger board is on the left at *F*. Around the base of the finger board is wound a

magnetic blow-out coil M, which, by way of fingers that contain a great deal of iron, projects lines of force across the arc gaps and extinguishes the arcs. The connecting board is in two sections; one section is at G in the right-hand part of the controller and the other is in the lower part, below the power drum. As is the case with all modern controllers, the 28A motor cut-outs are arranged so that when one motor is cut out, there is an interference with the power drum in such a way that it cannot be turned past the series notches. With one motor cut out, the 28A controller starts the car on the first notch and gives the single motor full power on the fourth notch. The power and reverse handles interlock as on the K2 and K11 types.

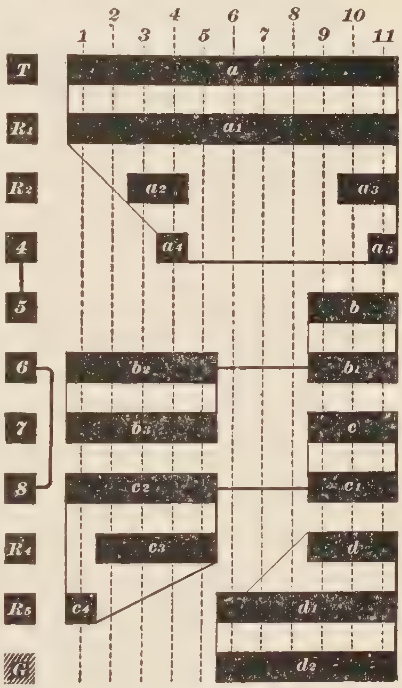


FIG. 32.

48. Fig. 32 shows the 28A power drum and the finger board on the left. This drum has four groups of rings; all rings marked a are connected together and should ring up together when tested with a magneto-bell; the same is the case with the rings marked b, c, and d; but groups with different letters are insulated from one another. The vertical dotted lines show the several positions assumed by the drum in going from the first notch to the last one.

49. The 28A Reverse Switch.—On the 28A reverse switch, as on any other, the position of the reverse handle

is supposed to indicate the direction in which the car will start as soon as the power drum is turned on.

Fig. 33 shows the connections of the 28A reverse switch. In this diagram, all the devices have been left out save the motors and resistances. All wires, instead of running to their respective controlling devices, as on a car, are here run direct to the reverse switch. The mechanical details of the moving parts of the switch are not shown in Fig. 33, but they can be understood by reference to Fig. 34, which shows the principle on which the switch operates. DD is a flat vulcabeston, slate, or fiber disk on the outside rim of which are screwed the brass tips T, T, T, T. Handle H is pivoted at O' and can be moved ahead or back, but in the figure it is in the off-position, in which position it can be taken out. Posts F_1-, A_1+, F_1+, F_2-, A_2-, and F_2+, in Fig. 33, are stationary; besides having connecting posts to which wires can be run, they have switch blades against which brass tips T, T, T, T, Fig. 34, press when the handle H, and hence the lever L, is moved one way or the other. When the handle H is shoved ahead to the right, the connections are as shown by the shaded lines in Fig. 33, where F_1+ is connected to post *9*, F_1- to A_1+, F_2+ to post *11*, and F_2- to A_2-. In this position, the path of the current from the trolley T to the ground G is T–R_1–R_2–R_3–*9* across one of the drum tips to post F_1+, out through the No. 1 motor field, back to post F_1-, across another drum tip to post A_1+, out through the No. 1 motor armature and back through resistance coil R_4–R_5 to post *12*, thence across the dotted line (which indicates that posts *11* and *12* are permanently connected,

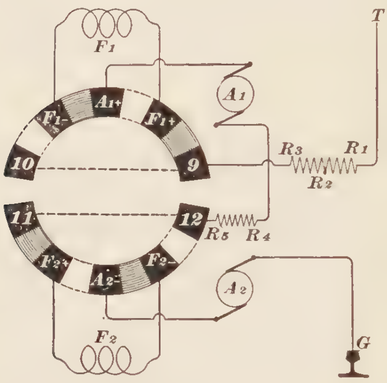


FIG. 33.

as are posts *9* and *10*) to post *11*, through a third drum contact tip to post F_2+, from where it passes out through the No. 2 motor field, back to post F_2-, across the fourth and last drum contact tip to post A_2-, through the No. 2 motor armature to the ground at *G*. This ground is secured by grounding the negative brush lead of the No. 2 motor directly to the frame of the motor or to the ground wire. If the reverse handle *H* is thrown back, the drum contact tips take up the position shown by the dotted lines in Fig. 33, and the former connections are broken. Posts F_1- and *10* are connected together, posts F_1+ and A_1+, F_2- and *12*, F_2+ and A_2- are also connected, and the path of the current from the trolley to the ground is T–R_1–R_2–R_3–*9*–*10*–F_1-, through the No. 1 motor field, F_1+–A_1+, through the No. 1 motor armature, R_4–R_5–*12*–F_2-, through the No. 2 motor field F_2+–A_2-, and through the No. 2 armature to the ground at *G*, as before.

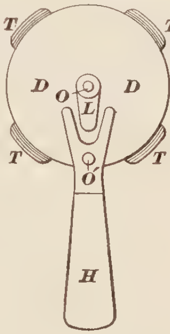


FIG. 34.

50. It should be noticed that when the reverse handle points ahead, the current enters the No. 1 motor field on the right-hand end and the No. 1 armature at the top brush holder; it goes into the No. 2 motor field at the left-hand end and into the No. 2 armature at the lower brush holder. When the reverse handle is thrown back, the current goes into the two armatures the same as it did before, but it goes into the No. 1 field at its left-hand end instead of the right and into the No. 2 field at the right-hand end instead of the left, as it did when the reverse handle was set to send the car ahead. The fields, then, have been reversed instead of the armatures, as on the General Electric equipment.

51. The 28A Cut-Out.—The 28A cut-out consists of two sets of posts, four posts for each motor, with holes in them to take a plug shaped to fit the holes. To operate the

cut-out, the plug is taken by the handle, pulled out part of the way, and given a quarter-turn; on releasing the plug, a spring pulls it back home into its new position. The lower plug is for the No. 1 motor, the motor next to the trolley wire, and the upper plug is for the No. 2 motor, the motor next to the ground.

In Fig. 35, both motors are shown cut in, in which position the plugs make contact between the posts that are up and down. For example, the lower plug connects posts *15* and *16* on one side and posts *13* and *14* on the other, the top plug connects posts *17* and *18* on one side and *19* and *20* on the other. Post *20* might just as well not be there, as far as being of any electrical use is concerned, because it is not connected to anything. It is put there not only to avoid having two sorts of cut-out devices in the controller, calling for two sorts of plugs, but it also serves as an additional mechanical support for the top plug, thereby making a good electrical contact more certain. In the position shown in Fig. 35, the path of the current is T–R_1–R_2–R_3–*13*–*14*–F_1+ –F_1- –A_1+ –A_1- –*15*–*16*–R_4–R_5–*17*–*18*–F_2+ –F_2- –A_2- –A_2+ to the ground at G.

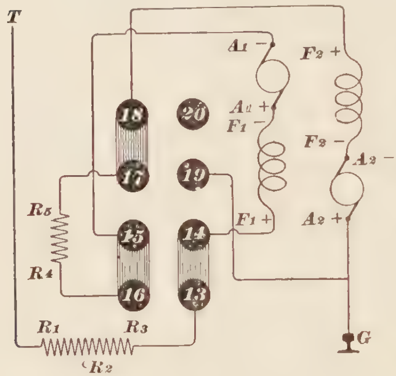


FIG. 35.

It will be noticed that the brush lead at which the current goes into the No. 2 armature is marked A_2-. Of course, the very fact that the current goes in at this brush holder makes it positive, but the lead is marked negative to indicate the fact that because the motors hang on the car truck back to back, their armatures must turn in opposite directions, in order to urge the car in the same direction, and if the current goes into both fields from the same end, it must enter the armatures at the front lead on one motor and at the back lead on the other.

52. In Fig. 36 the No. 1 motor is shown cut out; its plug has been given a quarter-turn, breaking all connection between posts *13* and *14*, and making a connection between the lower posts *13* and *16*, thereby leaving the two ends of the No. 1 motor, connected to posts *14* and *15*, hanging in the air, as it were. The No. 1 motor is, therefore, cut out because it can get no current. The path of the current in this case is $T\text{–}R_1\text{–}R_2\text{–}R_3\text{–}13\text{–}16\text{–}R_4\text{–}R_5\text{–}17\text{–}18\text{–}F_2+\text{–}F_2-\text{–}A_2-\text{–}A_2+$ to the ground at G.

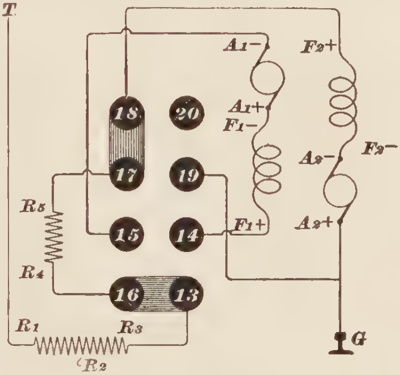


FIG. 36.

53. Fig. 37 shows the No. 1 motor cut in and the No. 2 motor cut out. In this case, a quarter-turn on plug No. 2 has broken the connection between posts *17* and *18* and made connection between posts *17* and *19* direct to the ground at G. One end of the No. 2 motor is left hanging in the air at post *18*, and the other end is grounded through its permanent ground connection. The motor is cut out and therefore dead. The path of the current in this case is $T\text{–}R_1\text{–}R_2\text{–}R_3\text{–}13\text{–}14\text{–}F_1+\text{–}F_1-\text{–}A_1+\text{–}A_1-\text{–}15\text{–}16\text{–}R_4\text{–}R_5\text{–}17\text{–}19$ to earth at G.

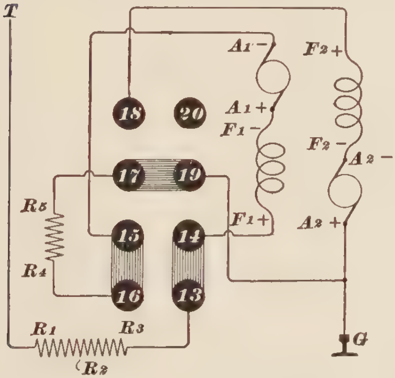


FIG. 37.

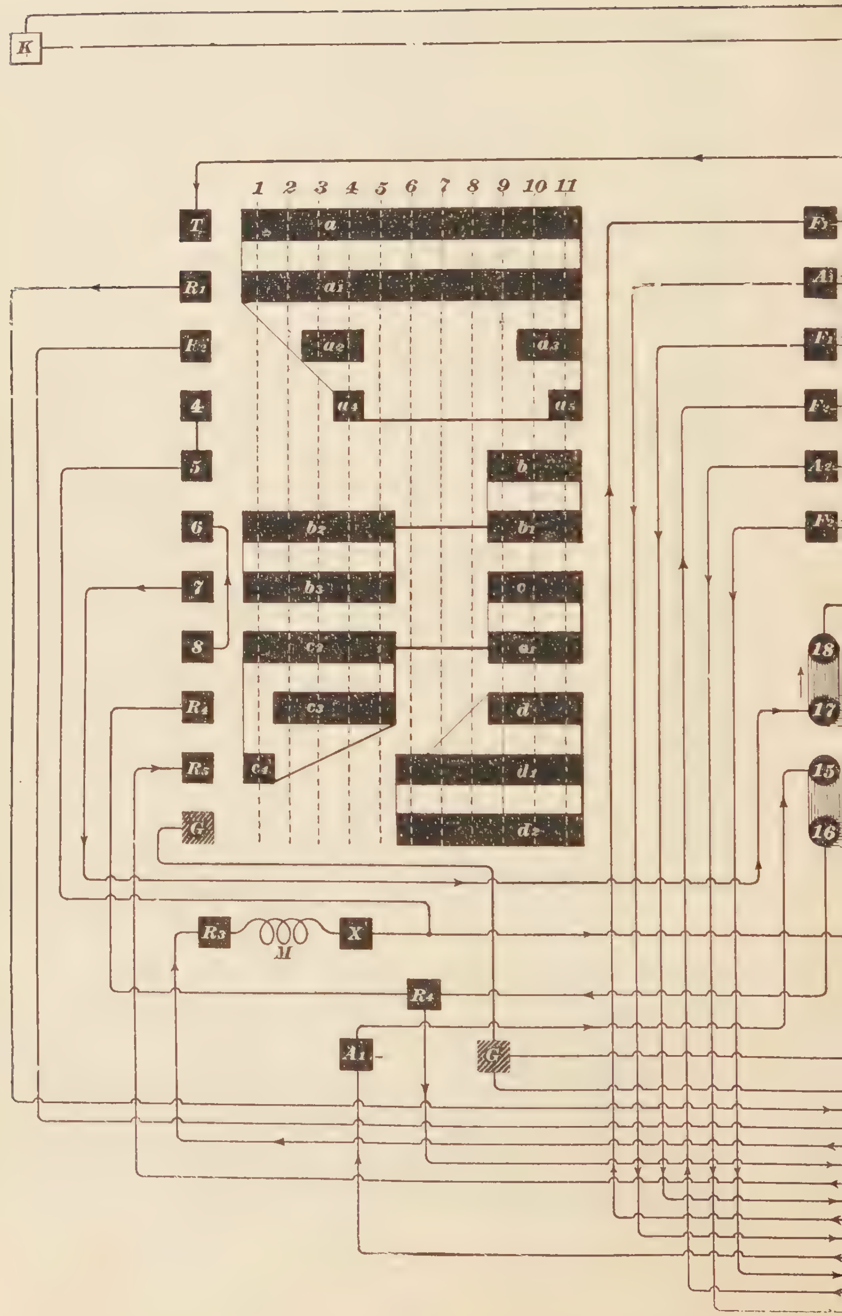
54. Car-Wiring Diagram.—Fig. 38 is a car-wiring diagram of the Westinghouse 28A controller. *K*, *K* are the

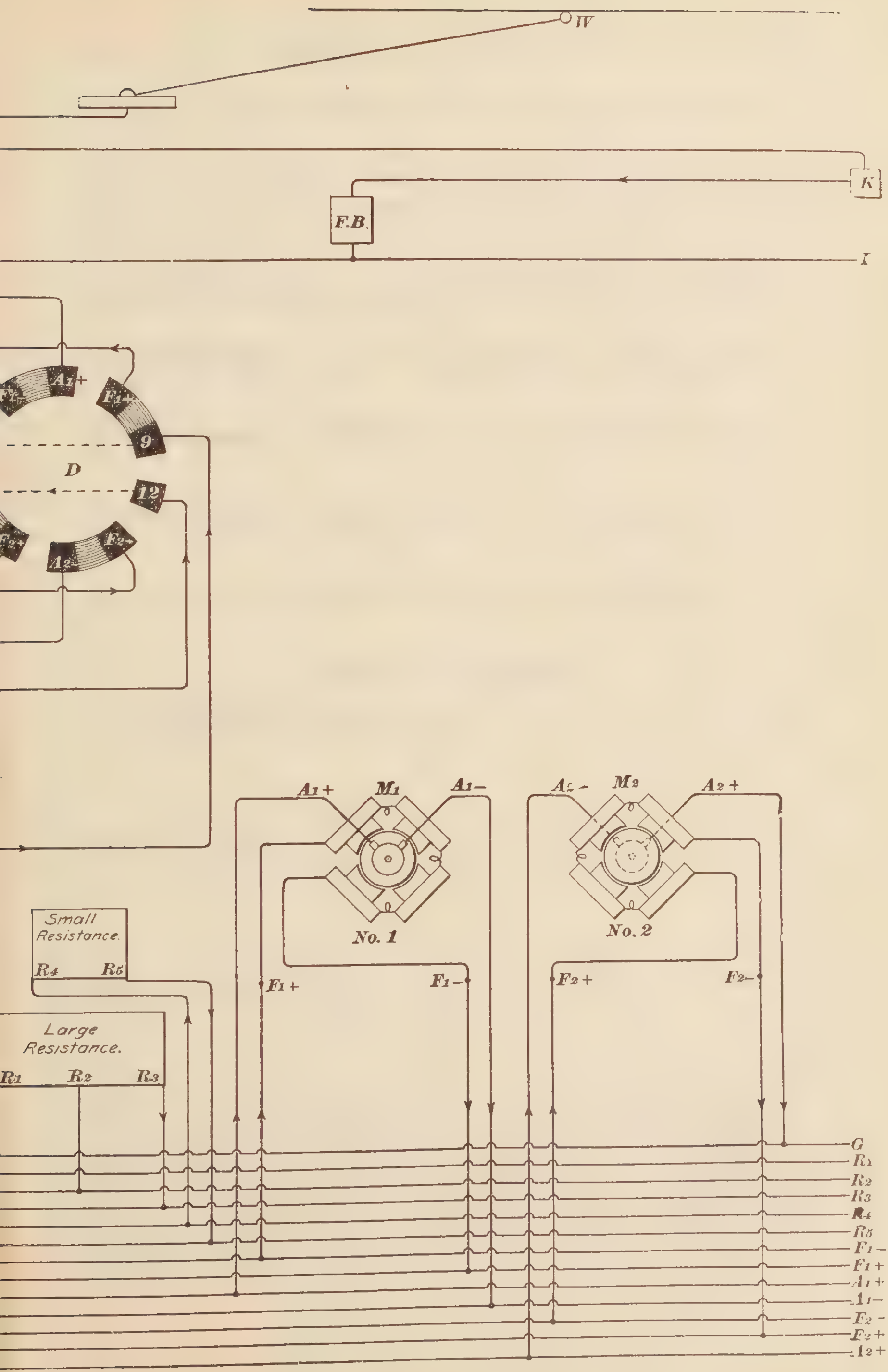
two hood switches; W, the trolley wheel; and FB, the fuse box; the lightning arrester is not shown; D is the reverse switch; L_1, the No. 1 motor cut-out switch; and L_2, the cut-out switch for the No. 2 motor; $R_4 R_5$ is the small one-part starting coil; and $R_1 R_2 R_3$ the large two-part starting coil; M is the magnetic blow-out coil that goes around the base of the finger board, as shown in Fig. 31; M_1 is the No. 1 motor or the motor through which the current first passes in its passage from the trolley wire to the ground; M_2 is the No. 2 motor or the motor next to the rail or ground.

55. Notes on Car-Wiring Diagram.—In Fig. 38, the cut-out plugs are shown turned so that both motors are cut in, and the dotted lines at L_1 and L_2 are not supposed to represent connections in this position of the cut-out plugs. The path of the current from the trolley wire to the ground on the first notch is W–K–K–FB–T–a–a_1–R_1, along the car wire, as indicated by the arrowhead, to the positive end of the large starting coil at R_1, through the large starting coil and out at R_3, along the R_3 car wire to post R_3 at the left, through the blow-out coil M–X–*13*–*14*–*9*–F_1+–F_1+–F_1+, through the No. 1 motor field, F_1-–F_1-–F_1-–A_1+–A_1+–A_1+, through the No. 1 motor armature, A_1-–A_1-–*15*–*16*, to post R_4; thence on the R_4 car wire to the R_4 post on the positive end of the small starting coil, through this coil and out at R_5 to finger R_5–c_4–c_2–*8*–*6*–b_2–b_3–*7*–*17*–*18*–*12*–*11*–F_2+–F_2+–F_2+, through the No. 2 motor field, out at F_2-–F_2-–F_2-–A_2-–A_2-–A_2-, through the No. 2 motor armature, out at A_2+, directly to the ground wire at G.

56. The two dotted circles in the diagram of the No. 2 motor indicate the fact that the motor is turned end for end, so that its commutator cannot be seen from the same end as can that of the No. 1 motor, whose commutator outline is, therefore, indicated by the full-line circles.

In Fig. 38, only one controller is shown connected up. To connect up the other one, it is only necessary to connect the broken-ended wires in the lower right-hand corner of the


K
1 2 3 4 5 6 7 8 9 10 11
T
a
R1
a1
R2
a2
a3
4
a4
a5
5
b
6
b2
b1
7
b3
c
8
c2
c1
R4
c3
d
R5
c4
d1
G
d2
F1
A1
F1
F2
A2
F2
18
17
15
16
R3
M
X
R4
A1
G


W
K
F.B.
I
A1+
F1-
F1+
9
D
12
F2+
F2-
A2-
A1+
M1
A1-
A2-
M2
A2+
No. 1
No. 2
Small Resistance.
R4
R5
Large Resistance.
R1
R2
R3
F1+
F1-
F2+
F2-
G
R1
R2
R3
R4
R5
F1-
F1+
A1+
A1-
F2-
F2+
A2+

38.

sketch to the posts marked the same as these wires are on their ends.

57. Fig. 39 shows the combinations effected by the 28A controller. The fourth and seventh are the running notches. In this controller it will be noted that the resistance is made up into two parts, one of which, R_1 to R_3, is connected, on the first notch, in circuit ahead of the No. 1

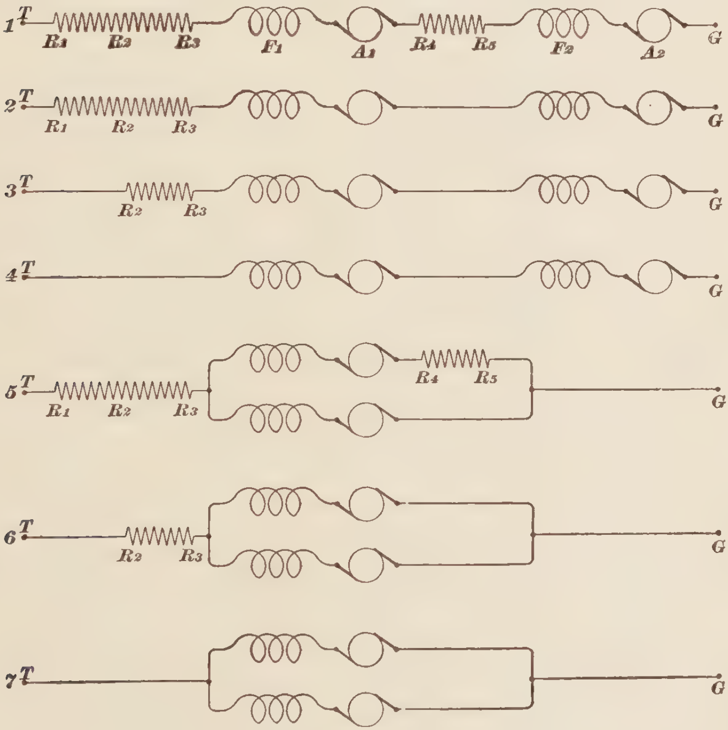


FIG. 39.

motor, and the other smaller part, R_4 to R_6, is connected between the two motors on the first notch. The controller differs in this respect from the General Electric controllers, where the resistance is all in one place. It makes very little difference where the resistance is put so long as it is included somewhere in series with the motors.

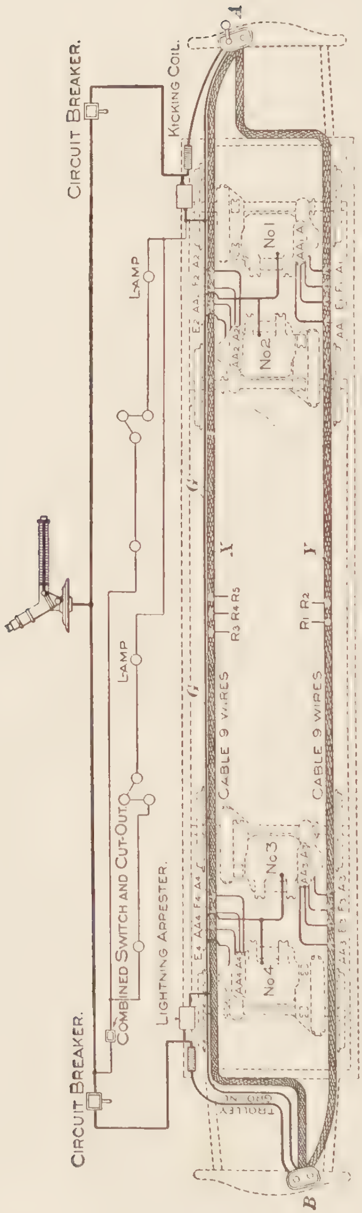


Fig. 40.

FOUR-MOTOR EQUIPMENTS.

58. The general tendency in electric railroading has been towards larger cars and higher speeds. In many cases, the comparatively short single-truck car has given place to the long double-truck car. These long cars may be equipped with either one or two motors on each truck. In some places, maximum-traction trucks, with a single motor on each, are used. In other places, ordinary four-wheeled trucks with a motor mounted on each axle are used. There has been much discussion as to whether four motors of moderate size are as economical as two larger motors. Tests have shown fairly conclusively that the four-motor equipment will use more current than the two-motor equipment under similar conditions; but with four motors, one on each axle, the whole weight of the car rests on the driving wheels, and it has been found that these cars can ascend grades, go through

snow, and run on slippery rails, where the two-motor equipment has great difficulty in maintaining its schedule time. This is an important consideration, and four-motor equipments are extensively used notwithstanding the fact that they take more current and are higher in first cost than two-motor equipments. The cost of repairs is also greater with the four-motor equipment.

59. General Arrangement and Method of Control. Fig. 40 shows the general layout of the wiring for a car equipped with four motors and General Electric K12 controllers. The motors, *1*, *2*, *3*, and *4*, are mounted back to back, two on each truck. The resistance coils are mounted under the middle of the car and are connected to the taps R_1, R_2, R_3, R_4, R_5. The two controllers A and B, the resistance coils, and the motors are connected together by wires run in the cables X and Y. Each of these cables is made up of nine-stranded rubber-covered wires pulled into canvas hose. $G\ G$ is the ground wire, which is not run in the hose. This ground wire is connected to the frames of all four motors, as shown in the figure. One end of the fields of motors Nos. 2 and 4 is also tapped to the ground wire.

60. The usual method for controlling a four-motor equipment is to connect the motors in pairs in parallel and then to treat the two pairs as if they were single motors, operating them by the series-parallel method, as with a regular two-motor equipment. This will be understood by referring to Fig. 41, which shows the various combinations effected by the K12 controller.

If the student will refer to the description of the K11 controller, he will see that the combinations given in Fig. 41 are practically the same as for the K11, except that here we have four motors in two pairs instead of the two single motors. No. 1 motor is connected in parallel with No. 3, and No. 2 with No. 4, so that a motor on one truck is connected in parallel with a motor on the other (see Fig. 40).

61. The K12 Controller.—The K12 controller used for the operation of four motors is similar in general appearance

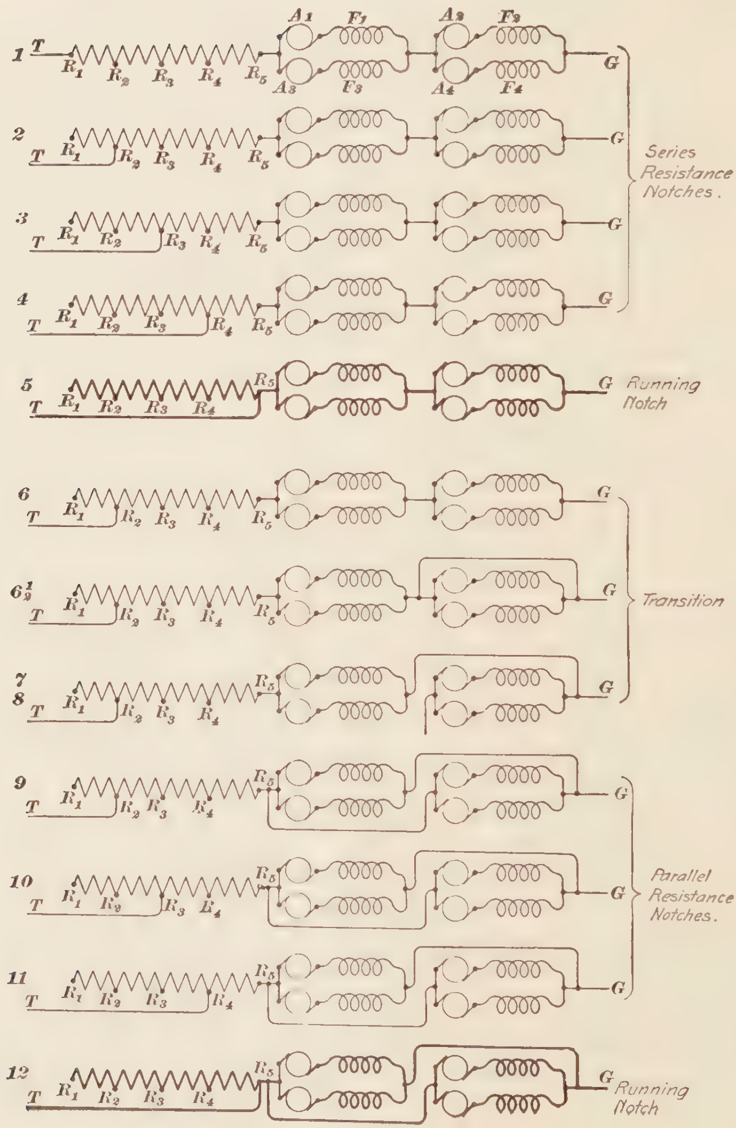
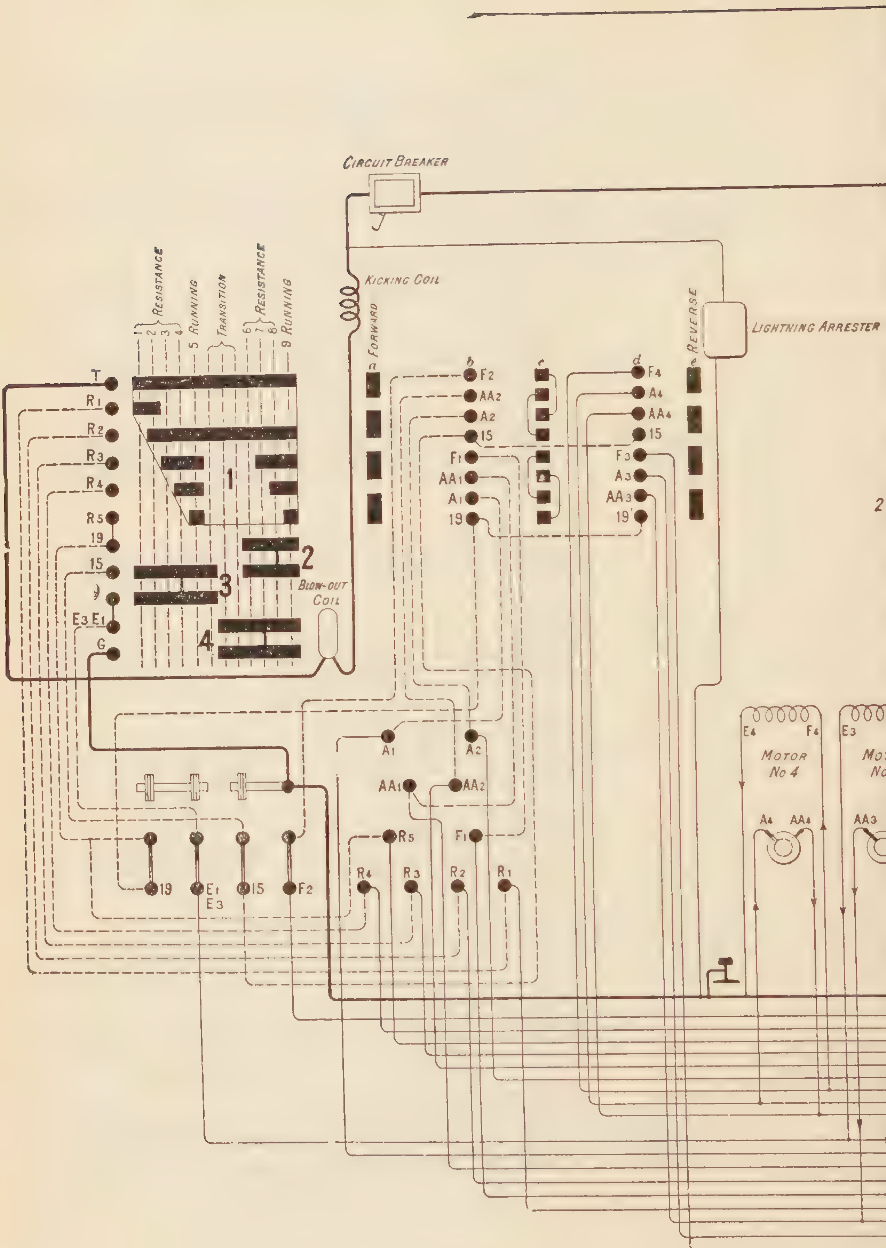
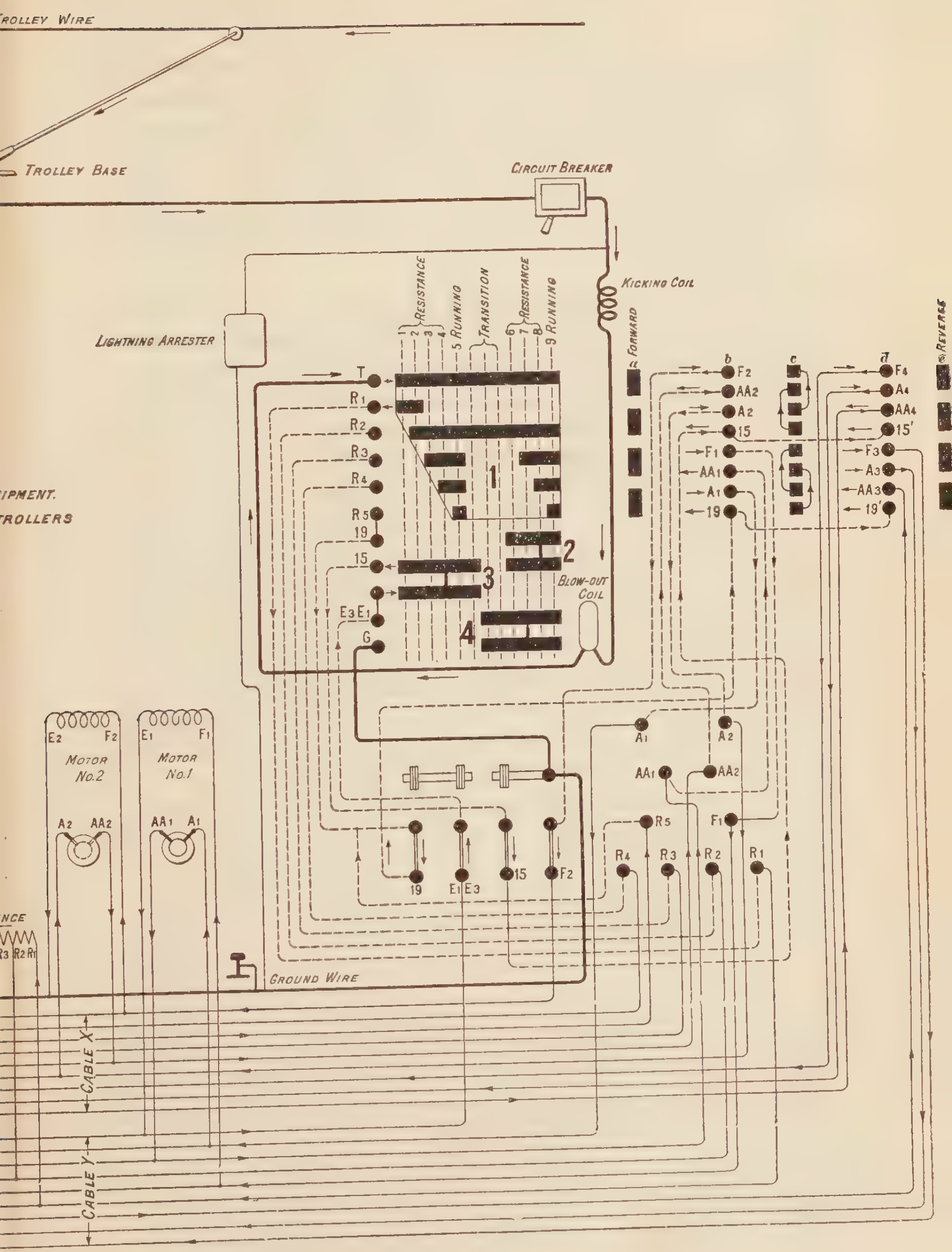

Series
Resistance
Notches.
Running
Notch
Transition
Parallel
Resistance
Notches.
Running
Notch

FIG. 41.



Circuit Breaker
Kicking Coil
Lightning Arrester
Resistance
Running
Transition
Resistance
Running
Forward
Reverse
Blow-out Coil
Motor No 4



TROLLEY WIRE
TROLLEY BASE
CIRCUIT BREAKER
KICKING COIL
LIGHTNING ARRESTER
RESISTANCE
5 RUNNING
TRANSITION
RESISTANCE
9 RUNNING
FORWARD
REVERSE
BLOW-OUT COIL
IPMENT.
TROLLERS
MOTOR No.2
MOTOR No.1
GROUND WIRE
CABLE X
CABLE Y

to the other type K controllers made by the General Electric Company. Its contact fingers and drum contacts are heavier than the K2 or K10, because the four motors require a large current. The use of the four motors requires some modifications in the construction of the reversing switch, but otherwise the controller is very similar to those just considered.

62. Fig. 42 is a wiring diagram for a car equipped with four motors and two K12 controllers. The power drum is very similar to that of the K10 controller, but a double row of contact fingers is provided on the reverse switch. When the car runs ahead, the reverse-switch fingers *b* are in contact with plates *a* and fingers *d* are in contact with *c*. When the car runs back, fingers *b* make contact with *c* and *d* with *e*, thus reversing the current in all four armatures. The leads E_2 and E_4 from the No. 2 and No. 4 motor fields are permanently connected to the ground wire. The main trolley wire connects to the blow-out coil, as shown. The student by this time should be able to trace out the path of the current on the various notches for himself, so that it will not be necessary to give the various combinations. The path of the current on the first notch is indicated by the arrows and is as follows, starting from post T at the power drum: $T–R_1–R_1–R_1$, through all resistance, $–R_5–R_5–19–19–$

$$\left\{\begin{array}{c} 19–A_1–A_1–A_1–A\ A_1–A\ A_1–A\ A_1–F_1–F_1–F_1–E_1–E_1–E_1–3 \\ 19'–A_3–A_3–A\ A_3–A\ A_3–F_3–F_3–E_3–E_3–E_1–3 \end{array}\right\}–$$

$$15–15–\left\{\begin{array}{c} 15–A_2–A_2–A_2–A\ A_2–A\ A_2–A\ A_2–F_2–F_2–F_2–E_2 \\ 15'–A_4–A_4–A\ A_4–A\ A_4–F_4–F_4–E_4 \end{array}\right\}–$$

Ground.

63. The other combinations are indicated by Fig. 41, and may be easily traced out on the diagram. When the cut-out switches are operated, the motors are cut out in pairs. For example, if something goes wrong with the No. 1 motor and the cut-out switch is thrown up, motors No. 1 and No. 3 are cut out. Four-motor cars require a large current; hence, care must be taken to see that the main wiring has plenty carrying capacity. The student will also

notice in Figs. 40 and 42 that the two circuit-breakers are connected in parallel, whereas the hood switches shown on the other diagrams are connected in series. This is the usual practice when circuit-breakers are used. The breaker on the front end is in while the car is running and the one on the rear end is left out, so that only one breaker is in use at the same time. If both breakers were in series, they would both trip in case a short circuit occurred, and the tripping of the one on the rear platform, in close proximity to the passengers standing there, would be undesirable; besides, it might not be convenient to reset the breaker on the back end, because the conductor would very likely be engaged in collecting fares. For these reasons, the breakers are connected in parallel instead of in series.

STREET-RAILWAY MOTORS.

64. A street-railway motor has to meet several conditions not imposed on motors that are used for stationary work. Its design is limited to a large extent by the space in which it is to be placed. It must go wholly beneath the car floor, and its width is limited by the gauge of the track. It must be dust-proof and waterproof, because it may have to run through all kinds of dirt and water. It must be arranged so that it can be readily suspended from the car axle. A railway motor must be substantial in every particular, because it is called on to stand harder usage than almost any other kind of electrical machinery.

As mentioned before, nearly all motors used for railway work are operated by direct current at 500 volts. The fields are connected in series with the armature, because the series-wound motor is capable of giving a strong starting effort and also gives a wide range of speed under varying loads. Moreover, the series-field coils, being wound with a few turns of coarse wire, are substantial and comparatively easy to repair. Alternating-current motors will, no doubt, be

used much more in the future for railway work than heretofore, but at present their application to this line of work is limited. The general construction of a street-railway motor is the same as that of any other direct-current motor. In other words, it must have a field magnet, armature, commutator brushes, etc. The field frame is made so that it will enclose the motor as much as possible. The earlier motors were only partly enclosed, but the later types are wholly enclosed. Access is allowed to the commutator and brushes by means of a hinged or removable lid.

65. Fig. 43 illustrates sections of some of the styles of field that have been used on street-railway motors. (*a*) is the style used on the old Thomson-Houston W. P. 50 (waterproof) motor. It is a two-pole field with a single magnetizing coil. (*b*) is the field used on the old Edison No. 14. It is a

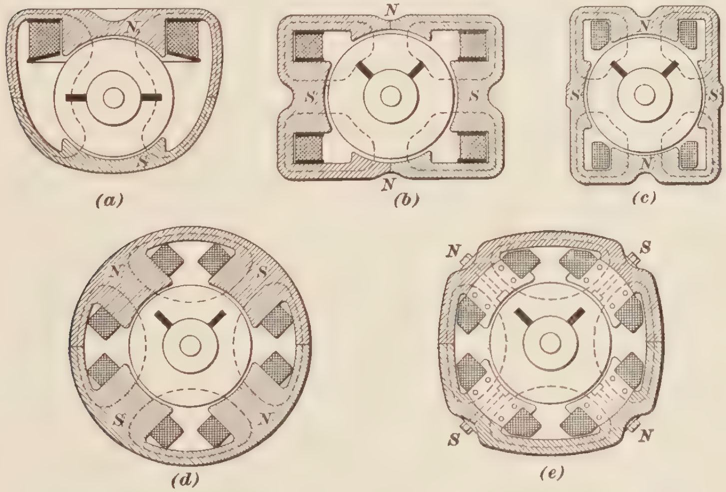


FIG. 43.

four-pole field with two field coils. (*c*) is the General Electric 800 (G. E. 800) motor field. It is similar to the Edison No. 14, but is turned up the other way. (*d*) shows the four-pole magnet frame introduced about 1891 by the Westinghouse Company in their No. 3 motor. It has four

poles set on the diagonal and each pole is provided with a field coil. This style of field has been used on nearly all street-car motors since, and practically all motors are now of the four-pole type, with their pole pieces set on the diagonal. Of course, the frame has been modified so as to enclose the motor and modifications have been made in the construction of the pole pieces. Cast steel has replaced cast iron for the magnet frame, allowing it to be made much lighter and stronger, but the fact remains that the frame and general construction of the Westinghouse No. 3 motor contain the main features of the motors as constructed at present. (*e*) shows a field about as used on a modern motor. Here the frame is of cast steel and can be made comparatively light. The pole pieces, instead of being cast with the frame, are built up of sheet-iron stampings and are bolted to the frame. This laminated pole construction reduces heating in the pole pieces and also tends to keep down sparking at the commutator.

Railway-motor armatures are of the slotted type. The coils are wound on forms and are then placed in slots on the core. In the earlier slotted armatures, a large number of slots were used, generally anywhere from 87 to 105. This was necessary because if the slots were made coarse, it was found that they caused the magnetism in the pole pieces to vary to such an extent that the solid poles would heat considerably. By laminating the poles, it has been found possible to reduce the number of slots to about one-third the number formerly used, thus making the slots very much larger, cheapening the cost of production, and making the motor operate better generally.

66. Speed Reduction.—It has not been found practicable or economical to drive ordinary street cars by means of direct-connected motors, i. e., by means of motors the armatures of which drive the axle directly without the use of any gearing. Such motors may be used where the motors are of large capacity, as on some electric locomotives, but in practically all cases geared motors are used. If the motor

drives the axle directly, the speed of the armature must, of course, be the same as that of the axle. This means that the motors must be designed for very low speed, and hence are heavy and bulky for their output. The heavy weight on the axles is hard on the track and the track joints are soon pounded out. For these reasons, the general practice is to use geared motors, so that the armature may be allowed to run four or five times as fast as the axle, thus keeping the size and weight of the motor for a given output within reasonable bounds. Direct-connected motors have been brought out and tried in connection with ordinary trolley cars, but they have not proved a success. They may, however, be used more in the future for the heaviest kinds of electric traction.

67. Speed Reduction.—When electric railways were first put into operation the motors ran at a much higher speed than those built at present, and it was necessary to transmit the power to the axle through an intermediate shaft. The small gear or pinion on the end of the armature meshed with a large gear on one end of the intermediate shaft, and a small gear on the other end of the intermediate shaft meshed with the axle gear. Motors of this kind were known as **double-reduction** motors, because of the double reduction in speed between the armature and the axle.

As the design of railway motors was improved, it was found possible to make efficient motors that would run slow enough to admit gearing direct to the axle, thus dispensing with the intermediate shaft. This is the kind of motor now almost universally used, and is known as the **single-reduction** type, because there is but one reduction in speed between the armature and the car axle. The ratio of the number of teeth in the gear to the number of teeth in the pinion gives the amount by which the speed of the axle is reduced as compared with the speed of the armature.

For example, suppose an axle gear has 65 teeth and the armature pinion 14 teeth; then the armature runs

$\frac{65}{14} = 4.64$ times as fast as the axle, because the armature has to make 4.64 turns for every turn that the axle makes. The **gear ratio** is, therefore, 4.64 : 1, the axle gear having 4.64 times as many teeth as the pinion. Various gear ratios are used in practice, depending on the size of the motors and on the speed at which the cars are to be run. If the cars are to run at a slow speed, the number of teeth in the axle gear will be large compared with the number in the pinion, and *vice versa*. The most common values of the gear reduction lie between 4 and 5. It will not be necessary to go into details regarding double-reduction motors, as they are no longer used. The number of different types and sizes of single-reduction motors in use is very large, and it would be an endless task to take up all of them. We will, however, take up two or three representative types, and the student will note that there is comparatively little difference between them so far as their general design is concerned. Motors are, of course, being improved all the time, but they have now reached a point where the changes are more in the line of improvements in details rather than radical changes in design.

GENERAL ELECTRIC MOTORS.

68. The General Electric Company have made a great variety of motors, some of the more common of which are the G. E. 800, G. E. 1,000, G. E. 1,200, G. E. 52, G. E. 54, etc. The numbers 800, 1,000, 1,200, etc. were given to these motors to denote the number of pounds drawbar pull that the motor could exert when taking full-load current and when mounted on 33-inch wheels. This method of rating the motors has now been dropped, and the machines are designated by arbitrary numbers, such as 52, 54, etc. The field used on the G. E. 800 and G. E. 1,200 is of the type shown at (*c*), Fig. 43. The G. E. 1,000 has four poles arranged on the diagonal, as shown in Fig. 43 (*e*). The

poles are, however, not laminated, but consist of steel castings bolted to the frame, and the armature is therefore provided with a large number of small slots. The G. E. 1,000, G. E. 52, and G. E. 54 are much the same in general appearance. We will select the G. E. 52 motor for illustration.

G. E. 52 MOTOR.

69. Motor Frame.—Fig. 44 shows the general appearance of the G. E. 52 motor. The general shape of the field frame is hexagonal; it is made in halves, which are held together by bolts. The two arms *b*, *b* extending from the back of the motor receive one-half the axle bearing, which is in the shape of a split bushing. The axle-bearing caps *c*, *c*

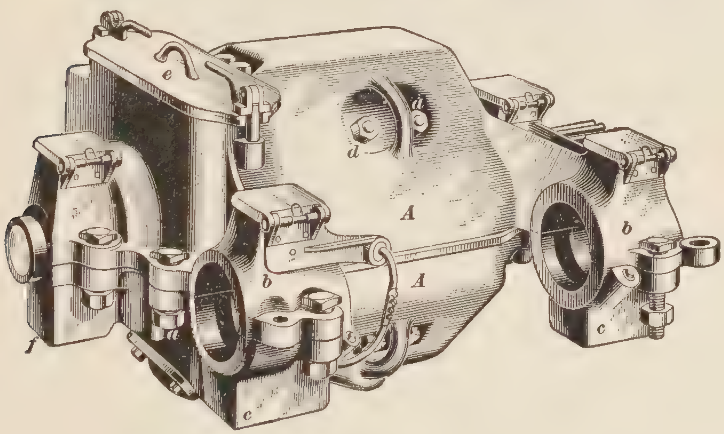


FIG. 44.

are provided with grease boxes, and the grease or oil is fed on the axle by means of pieces of felt from underneath as well as from the grease cups on top. The bolts *d*, *d* hold the pole pieces and field coils in place. The removable cover *e* allows access to the commutator and brush holders. The lower armature-bearing caps *f* are separate from the lower half field *A*, and by leaving these caps in position, the

lower half field *A* may be swung down, leaving the armature in the upper half, as shown in Fig. 45. The lower half field is here swung down and the two lower pole pieces are exposed for repair or inspection. By removing the bearing

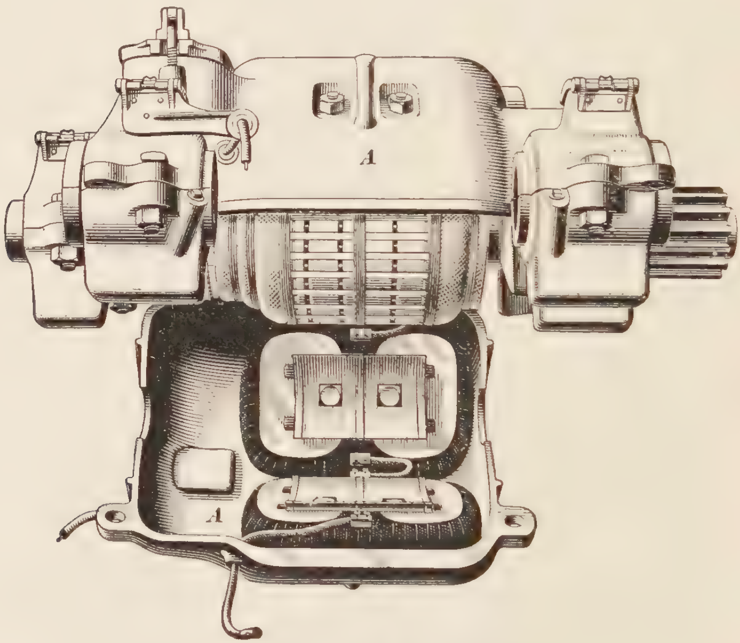


FIG. 45.

caps, the armature can be lowered with the field, thus leaving the upper field coils and pole pieces exposed, as shown in Fig. 46. Most modern motors are constructed in this way, because it is a great convenience in inspecting and repairing the motors.

70. Capacity of G. E. 52 Motor.—The G. E. 52 motor has an output of 27 horsepower. This means that it will develop 27 horsepower continuously for 1 hour, and at the end of the hour the temperature of the windings will not be more than 75° C. above the temperature of the

surrounding air. The motor is intended for ordinary street-railway work and is not recommended for the heavier kinds of traffic.

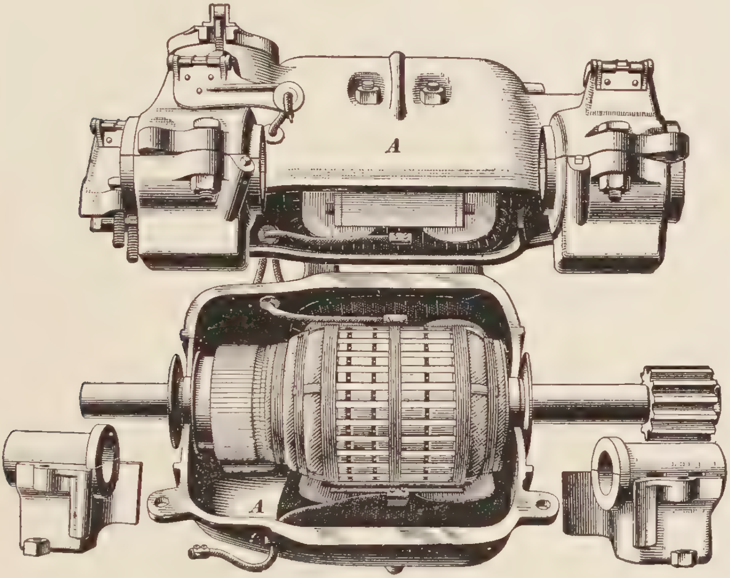


FIG. 46.

71. Pole Pieces.—The motor has four poles provided with flanged pole pieces that are laminated; the flanges serve to hold the field coils in place, and the laminations not only do away with a great deal of heat in the pole piece, but from the way in which they are built up, they produce a magnetic field that does away with much of the sparking at the brushes. The pole pieces are made of iron plates shaped

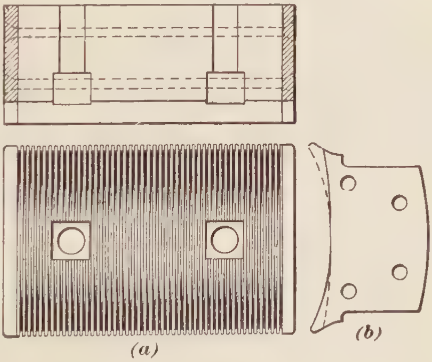


FIG. 47.

something like the full-line part of Fig. 47 (*b*). The pole pieces are built up of these plates, every other one of which is turned end for end. The result of this manner of construction is shown in Fig. 47 (*a*), where, along the horizontal center part of the pole piece, the plates are close together, but on the horns only half of the plates come out on each side. This plate construction, to a great degree, does away with sparking at the brushes, because the thinning out of the metal on the horns of the pole pieces produces what is called a *shaded field* or *fringe*. This means that the pole-piece horns are so made that the lines of force are distributed in such a way that they gradually become thinner and thinner at the proper rate and in the right place. This shaded field provides a fringe that reverses the current in the coil passing under the brush, and hence brings about the change in the direction of the current with but little sparking.

72. Field Coils.—The field coils are wound on forms, and while the asbestos-covered wire is being wound it is treated with a mixture of chalk and japan and afterwards baked. The coils are heavily insulated with tape and insulating varnish and are given a glazed surface that will readily turn off water and prevent moisture getting in.

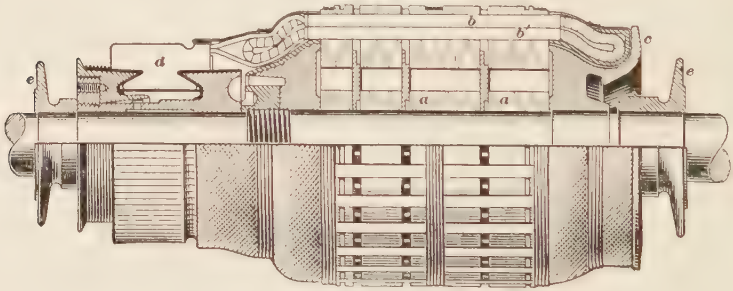


FIG. 48.

73. Armature.—Fig. 48 shows a half section of the G. E. 52 armature, and its construction is typical of many of the railway-motor armatures now in use. The core is provided with 29 slots. One side of 6 coils goes into each slot,

so that there are 87 coils altogether, and the commutator has 87 bars. The coils are bunched in groups of three, and one side of one bunch goes into the bottom of a slot, one side of another into the top of the same slot. In Fig. 48, *a a* is the laminated armature core and *b*, *b'* the upper and lower halves of two different coils lying in the same slot. The ends of the coils, where they project from the core, are supported and protected by the end shield *c*. The leads from the coils are connected to the commutator bars *d*, which are mounted as shown. The flanges *e*, *e* are for preventing grease and oil working their way into the armature. The bearings are so arranged that any oil getting on *e*, *e* drops through an opening to the street.

74. Brush Holders.—Railway-motor brush holders are fixed permanently at the neutral point and are not arranged so that they can be shifted, as is the case with many other direct-current machines. The reason for this is twofold. In the first place, the motor has to run in either direction, and in the second place, the variations in load are so sudden that any brush-shifting arrangement is out of the question. The brushes are, however, mounted so that they can be moved radially towards the center of the commutator as the latter wears away.

Fig. 49 shows the brush holders and brush-holder yoke of the G. E. 52 motor. The yoke *a*, which is made of well-seasoned hard wood treated with insulating material, is bolted to the upper field frame by means of bolts *b*, *b*. The brush holders *h*, *h* are bolted to brass slides on *a* by means of bolts *c*, *c*. All railway motors use carbon brushes, and in this case, two brushes $2\frac{1}{4}$ in. $\times$ $1\frac{1}{4}$ in. $\times$ $\frac{1}{2}$ in. are used in each

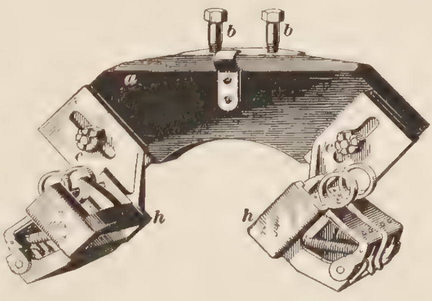


FIG. 49.

holder. The brushes are radial, i. e., they point towards the center of the commutator, so as to work equally well for either direction of rotation of the armature.

75. Gears.—The standard gear for the G. E. 52 motor has 67 teeth and the pinion 14 teeth, making a gear reduction of $\frac{67}{14} = 4.78$ to 1. Fig. 50 shows the motor mounted on the axle complete with its gear case shown at the left. All modern motors are provided with gear cases that are

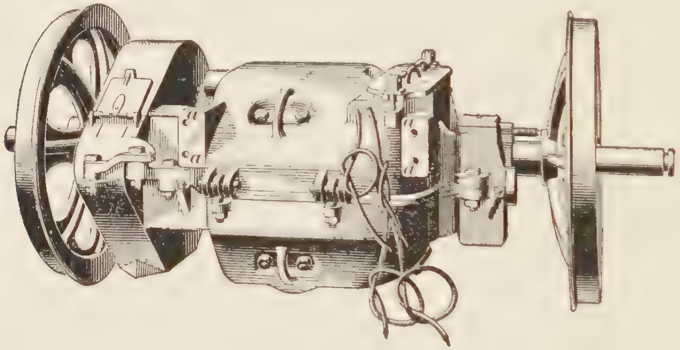


FIG. 50.

kept partly filled with soft grease or oil. This greatly prolongs the life of the gears by keeping them well lubricated and by shutting out dirt and gritty material. The holes *a*, *a* receive the bolts for attaching the suspension bar that is used to hold the motor in place.

76. Nose Suspension.—Fig. 51 shows another view of the suspension. This is the ordinary **nose suspension** so widely used. *P* is the small gear or pinion, *G* the axle gear, and *W* the car wheels. The back of the motor is supported by the axle and the front is held up by means of a cross-bar or yoke bolted to the front of the motor and resting on springs supported by the side frames of the truck. The arms cast on the motor frame hold the gears at the proper distance from center to center, while the outer part of the

motor is free to rise up and down. The motor is thus supported flexibly, and there is not nearly as much pounding

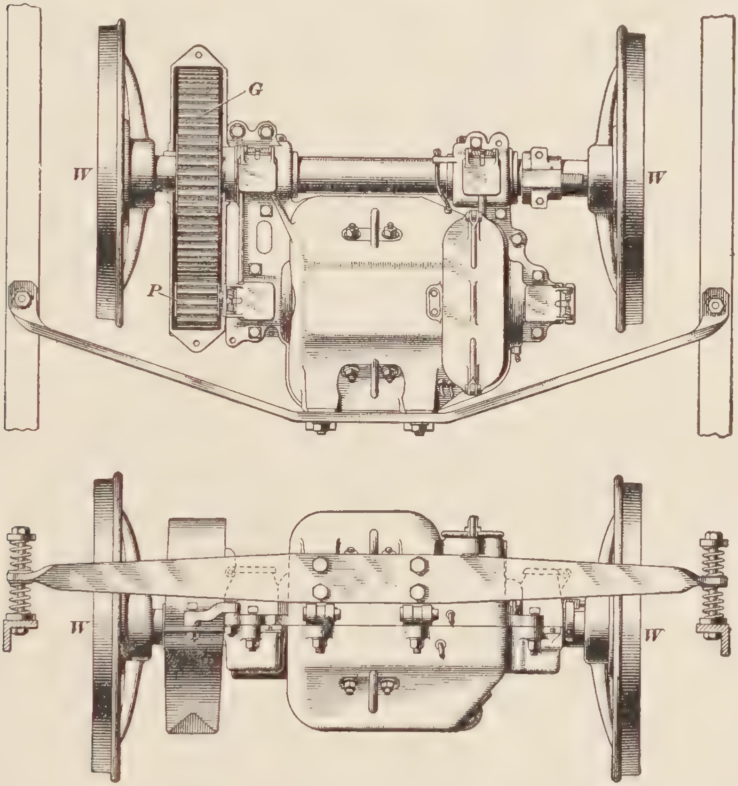


FIG. 51.

action as if it were mounted directly on the axle. The weight of the G. E. 52 motor without axle gear and case is 1,460 pounds.

WESTINGHOUSE NO. 56 MOTOR.

77. The Westinghouse No. 56 motor is intended for the heavier kinds of street-railway work. It is intended for interurban or cross-country traffic or for any service where

heavy cars are operated at high speed. Fig. 52 shows the motor closed, and it will be seen that its construction is much the same as the motor previously described. A, A' are the top and lower halves of the field frame, which is made of mild cast steel. The lid C may be thrown back to get at the commutator and brushes. The armature leads are shown at a, a' and the field leads at f, f'. Post g is used for making the connection to the ground. The lug l is used to hang the motor when the nose suspension is used. Sometimes the motor is supported by side bars or by a cradle that passes through the rectangular openings r at

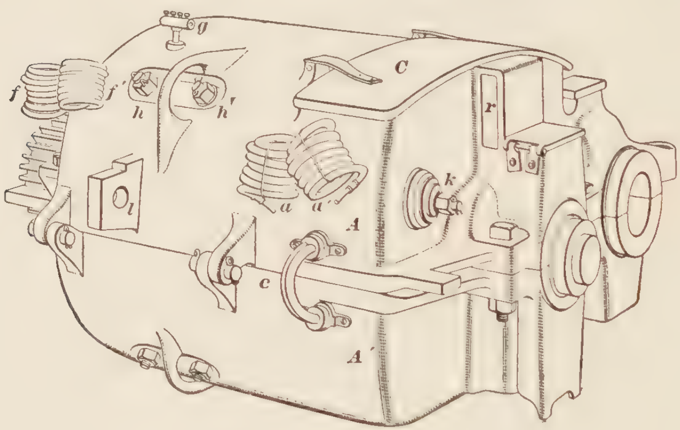


FIG. 52.

each end of the motor. The wires shown at c connect the top and bottom field coils together. The pole pieces are laminated and held in position by the bolts h, h', and the armature bearings are so arranged that the armature may be either swung down with the lower half or retained in the upper half. The bearings are provided with grease cups on the top and wick lubrication below. In this motor the brush holders are bolted to the frame, but, of course, are thoroughly insulated from it. One of the bolts for attaching a holder is shown at k. The total weight of

the motor, not including the axle gear and gear case, is 2,680 pounds.

78. Cradle Suspension.—Fig. 53 shows the **cradle suspension** as applied to the Westinghouse No. 56 motor. The front of the cradle *A A* is supported at *C* by the cross-beam *D*, which is supported by the side frames of the truck. The back end of the cradle is supported by springs *S*, *S'*, which bear on lugs cast on the same arm that carries the axle bearing. The cradle passes through the lugs on the ends of the motor, and the use of the springs insures a flexible suspension.

79. Capacity of No. 56 Motor.—Different makers have different ways of rating the capacity of their motors. Some rate them at the power they are capable of developing for a run of one hour without their temperature rising more than 75° C. above that of the surrounding air. Of course, the current taken by a motor in actual service is very variable, and the voltage at the terminals of the motor is also variable. For example, when the two motors are in series, each motor will get about 250 volts if the line voltage is 500. When the car is coasting or standing still, the voltage applied to the motors is zero. The average voltage applied to a motor throughout the day will not likely be more than 250 or 300 volts, and the No. 56 motor will carry a load of 50 amperes *continuously* at a pressure of 300 volts with a rise in temperature of 75° C. Of course, much larger currents than this can be carried for short intervals, as, for example, when a car is starting up and getting under headway. The motor can carry a current of 100 amperes for over an hour without increasing the temperature over 100° C., provided it starts at 25° C. With 100 amperes, a tractive effort of over 1,600 pounds would be exerted with the motor mounted on 33-inch wheels. The continuous output of a railway motor, like any other electric motor, is limited by the heating. Railway motors are generally worked at a fairly high temperature, because they must be enclosed to such an extent that free ventilation is difficult.

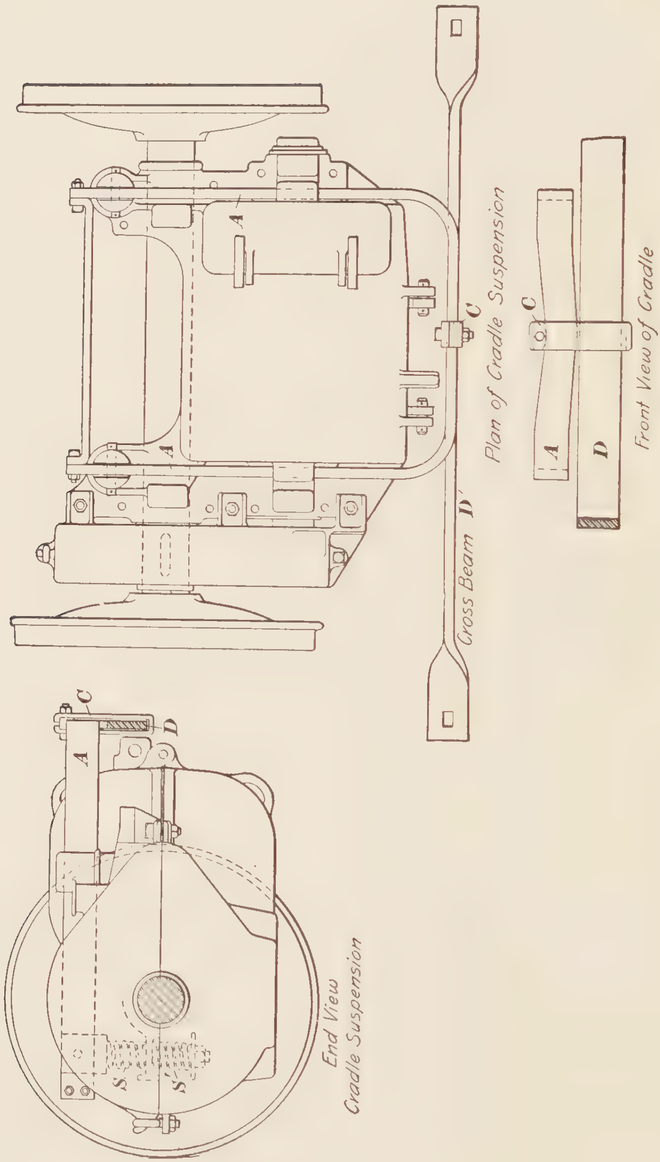

A
A
C
Plan of Cradle Suspension
Cross Beam D'
C
A
D
Front View of Cradle
C
A
D
S
S'
End View
Cradle Suspension

FIG. 53.

RAILWAY-MOTOR ARMATURE CONNECTIONS.

80. There are so many different styles of railway-motor armatures that it will not be possible to take up the methods of connecting the different kinds in detail. The following will, however, give some general directions relating to these connections. These all relate to four-pole machines and the coils span over about one-quarter of the armature. They also refer to drum-wound armatures exclusively, as ring armatures are not used to any extent on modern railway motors. In former times, the cores were separately insulated and the wire was wound on from a reel; these armatures were known as *hand-wound armatures*. At present, the core insulation is confined to insulating disks on the ends, a strip of insulation in the bottom of each slot, and pieces of insulation, in some cases, on the sides of the slot. The coils are wound first on coil machines and then insulated and pressed to a shape to fit the slot. By using form-wound coils, much less skill is required to repair or rewind armatures. The first step was to have a slot for each coil; the next step was to bunch two coils together in one insulating casing or armor, so that the armature core had but one-half as many slots as there were coils. This practice left two empty half slots that had to be filled with a dummy coil (i. e., a coil whose ends were insulated instead of going into the commutator), so the scheme of using 2 coils in a case was abandoned in favor of grouping 3 coils in a case, so that a core need have but one-third as many slots as coils.

81. Modern street-railway armatures are of the series-connected type; that is, although a machine may have four poles, the armature is so connected that it has but two paths through it, and therefore requires but two brush holders. On an enclosed motor, four brush holders would be out of the question, because the bottom ones could not be inspected and it would be almost impossible to replace a brush if the motor were hot. Another point to bear in mind is that some motors have their pole pieces on the diagonal, while others

have them on the vertical and horizontal, with the result that on the former type, the brushes are set on the commutator at points opposite the centers of the pole pieces instead of being set at points midway between them corresponding to the position of the neutral line. This is necessary from the fact that if the brushes were set at the neutral line, one would be on top and the other would be down on one side, where it would be hard to get at.

82. Connections for a 99-Coil Armature.—Fig. 54 shows an armature having 99 coils and slots, its pole pieces being horizontal. The coil for this armature would have one short lead and one long one, and would be of such a width that one side could drop into slot *1* and the other side into slot *26*; the short lead would then go straight down to

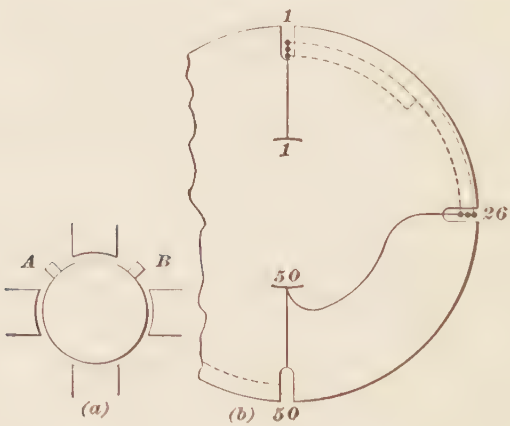


FIG. 54.

the commutator bar immediately in line with it and the long lead would go to the bar as nearly diametrically opposite as possible. This would be bar *50*. The next coil would drop into slots *2* and *27* and its leads would go to bars *2* and *51*. This is a rule that holds good on any armature having 99 slots and 99 coils where the four poles are on

the horizontal and vertical, as, for example, on the G. E. 800 or 1,200 motors. To make it hold good on armatures having 99 coils, 99 bars, but only 33 slots, it is only necessary to count off as if each coil had its own slot or as if there were no slots at all. For instance, suppose there are only 33 slots; then, one side of coils *1*, *2*, and *3* will be in slot *1*; *4*, *5*, and *6* in slot *2*; *7*, *8*, and *9* in slot *3*; and so on, so that the other sides of coils *1*, *2*, and *3*, which formerly fell into slots *26*, *27*, and *28*, when there was a slot for each coil, must now drop into slot *9*; the other sides of coils *4*, *5*,

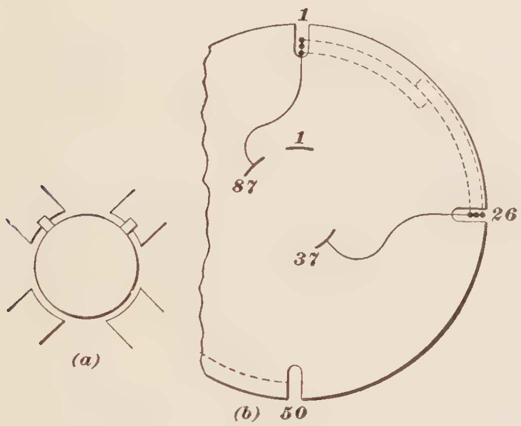


FIG. 55.

and *6* in slot *10*; and so on. The short lead of coil *1* goes to bar *1* and the long lead to bar *50*, as before. After one coil is installed, the others follow the same course.

Fig. 55 shows the connections for an armature having 99 slots and 99 coils, with the pole pieces on the diagonal. It will be noticed that in both cases, the brushes fall in the same place. In Fig. 55, however, the lead out of slot *1*, instead of going to bar *1*, directly opposite, goes to bar *87*, obtained by counting to the left 14 bars, including bar *1*; 99 is not divisible by 8, so that this is as nearly one-eighth a circumference as it is possible to get. Since the lead

coming out of slot *1* is shifted $\frac{1}{8} \times 99$ bars to the left, so must the lead out of slot *26* be shifted the same amount, so that instead of going into bar *50*, it goes into bar *37*, which is 14 bars to the left, counting bar *50*. In practice, the two bars are located as follows: The coil is dropped into slots *1* and *26*; begin with bar *1*, opposite coil *1*, and count 14 to the left, including *1*; this fixes one end of the coil in bar *87*; then, including bar *87*, count 50 bars to the right, which fixes the other end of the coil in bar *37*. After one coil is in, the others are easily placed. This scheme of bringing the connections around one-eighth a circumference to the left is called *giving the connections a lead.** It is nothing but a mechanical trick for bringing the brushes into the right place, and is used on all street-railway motor armatures whose pole pieces are on the diagonal. In Fig. 54, one lead is longer than the other, so that they are readily distinguished by their length; in Fig. 55, the leads are about the same length, so that to distinguish them, it is the practice to slip a piece of black hose on one, the other being white. Fig. 55 can be followed in assembling and connecting any armature that has 99 coils and either 99 slots or 33 slots, if the pole pieces are on the diagonal.

83. Connections for a 95-Coil Armature.—Figs. 56 and 57 give the general scheme for winding and connecting any armature having 95 slots and 95 coils for vertical and diagonal pole pieces, respectively. In Fig. 56, the coils drop into slots *1* and *25*, as before, but the lead out of slot *1* goes straight down to bar *1* and the other end of the coil in slot *25* goes half way around the commutator to bar *48*. In Fig. 57, one side of the coil goes into slot *1* and the other side into slot *25*; the bar in front of slot *1* is bar *1*. Including bar *1*, count off 13 to the left; this fixes the lead coming out of slot *1* in bar *84*. Including bar *84*, count off 49 bars to the

* The term "lead" as applied here should not be confused with the term "lead" as applied to a wire or terminal. In connection with armatures, dynamos, etc., the term "lead" (pronounced "leed") is commonly used to denote a terminal wire—such as the terminal of an armature coil—a wire running from a dynamo to the switchboard, etc.

right; this brings us to bar *37*, which takes the other end of the coil coming out of slot *25*.

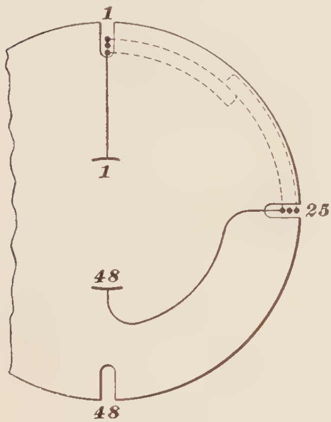


FIG. 56.

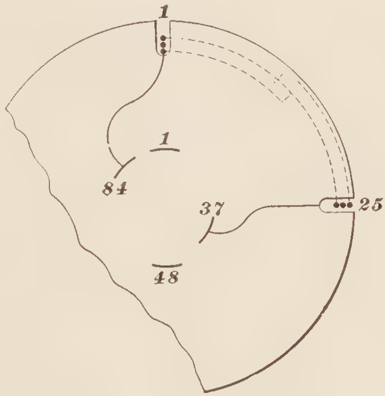


FIG. 57.

84. Connections for a 93-Coil Armature.—Figs. 58 and 59 show the scheme for winding and connecting any armature having 93 coils and bars and 93 or 31 slots for vertical and diagonal pole pieces, respectively. In both cases,

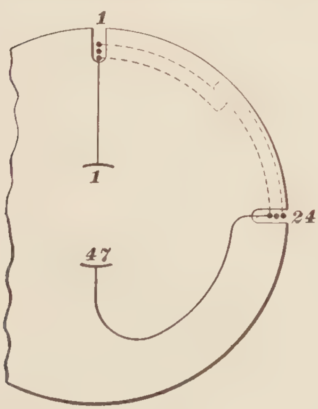


FIG. 58.

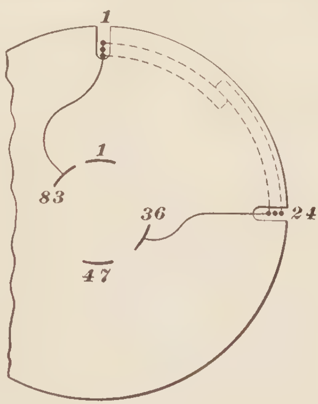


FIG. 59.

the coil drops into slots *1* and *24*. In the first case, the lead out of slot *1* goes straight down to bar *1* and the lead from

the same coil in slot *24* goes half way around and connects to bar *47*. In the second case, the lead from slot *1* goes into bar *83*, which is found by counting off 12 to the left of bar *1* and including it; the other end of the same coil in slot *24* connects to bar *36*, obtained either by going half way around the commutator from bar *83* to the right or by counting off a throw of 12 back from bar *47*.

85. Connections for a 105-Coil Armature.—Figs. 60 and 61 show, respectively, the vertical and diagonal methods of winding and connecting an armature having 105 slots, bars, and coils. In both cases, the first coil drops into slots *1* and *27*. In the first case, the lead out of slot *1* goes straight down to bar *1* and the other end of the same coil

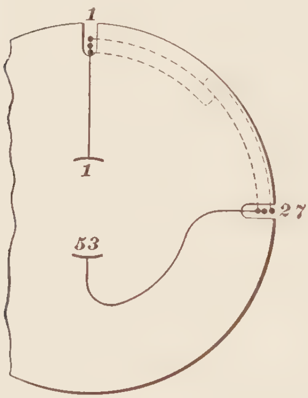


FIG. 60.

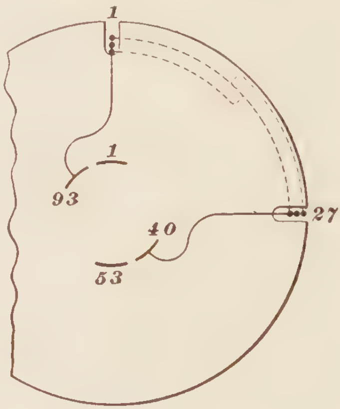


FIG. 61.

coming out of slot *27* goes half way around to bar *53*. In the second case, count off a throw of 14 bars to the left from and including bar *1*, which gives bar *93*, the bar for the lead out of slot *1*. To get the bar for the lead of the same coil out of slot *27*, count off 53 to the right from bar *93*, which gives *40*.

86. Connections for Armature With 93 Coils and 47 Slots.—Fig. 62 shows the scheme for connecting up for diagonal pole pieces an armature having 93 bars and coils

but only 47 slots; the single coils are done up into cells or cases, two coils to a cell; there are 47 of these cells, so there will be 1 coil (2 ends) more than there are places in the commutator. This extra coil might just as well be left out, so far as doing any work is concerned, for its ends are taped up so that they cannot come in contact with any other parts of the winding, but it is put in to preserve the mechanical balance of the armature. As shown in the figure, the coil drops into slots *1* and *13*. To connect the armature, pick out any coil and find both ends of it with a magneto or lamp circuit. Standing at the commutator end, call the end on the left *1*. With a straightedge, find the bar immediately in front of it; call this bar *1*, and count off 13 to the left; this fixes the left-hand lead at bar *82*. The other lead goes into the bar half way around the commutator or bar *35* to the right.

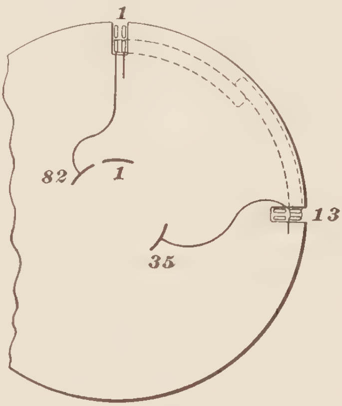


FIG. 62.

87. In all these winding diagrams, the student will note that one side of the coil occupies the bottom of a slot, while the other side of the same coil is in the top of a slot about one-fourth of the distance around the armature. By arranging the coils in this way, the crossings at the ends of the armature are easily disposed of, and in nearly all modern railway motors this arrangement is adopted.

There are many different styles of armature windings for railway motors, and for this reason it has been thought best to take up general principles that may be applied to any of them rather than particular cases. Practically all railway motors use windings that are, in general, similar to those described, although the exact grouping of the coils in the slots may be somewhat different.

RAILWAY-MOTOR FIELD CONNECTIONS.

88. One of the most common sources of trouble in connection with street-railway motors is wrongly placed or connected field coils. Few have any idea of the great amount of trouble a wrongly connected field coil may cause. Its effect is felt long after the trouble has been found and removed. A wrongly connected field not only injures itself, but it injures the other field coils and the armature. The armature probably heats to such an extent that it throws solder and the fields gradually bake inside, with the result that the car is soon turned in for blowing fuses. The chances are that before the trouble is discovered and removed, there may be two or three grounded brush holders, armatures, or fields, due to the current jumping across to the frame of the motor, because the weak fields in the first place cause poor commutation, and in the second place reduce the counter E. M. F. and allow more current to flow than the brushes can stand. It is safe to say that one-half of the trouble on cars turned in for blowing fuses can be traced directly or indirectly to defects in the field coils.

89. General Remarks on Field Coils.—Fig. 63 shows a section through the middle of a four-pole motor having top and bottom field coils. The halves of the shell come

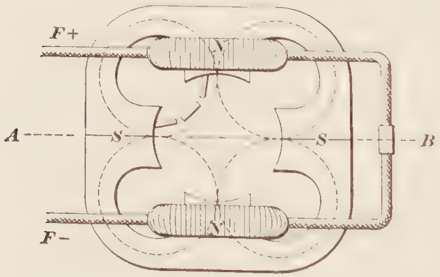


Fig. 63.

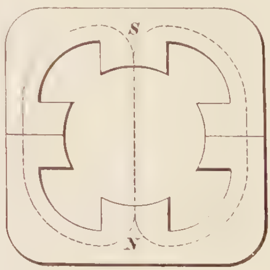


Fig. 64.

apart along the line *A B*. In Fig. 63, the two coils are connected correctly, and the general path of the lines of force forms the curved four-sided figure at the center. In Fig. 64, the two field coils have been left off to simplify the drawing,

but the figure is supposed to be the same as Fig. 63, except that the two coils are connected incorrectly, so that opposite poles are of opposite polarity and the side pole pieces cease to be poles at all. The lines of force pass across the armature core just as they would in a regular two-pole machine, with the result that the neutral point falls midway between the brushes, which are in an active part of the field, and therefore spark a great deal even when the car is run with the two motors in series.

Fig. 65 shows a section through a four-pole motor that has a coil on each of its poles. The coils are so connected that the pole pieces alternate in polarity. Fig. 66 is the same as Fig. 65, but the field coils are not shown. The top left-hand field coil is supposed to be connected incorrectly, with the result that the motor has three south poles and only one north pole, and the lines of force are very much twisted out of their path. However, it will be noticed that two sides of the four-sided figure made by the path of the lines of force can still be seen. Part of the armature is, therefore, effective, and, as a matter of fact, if one coil out of four is wrongly connected, the car will continue to start and run on the faulty motor, but the brushes will spark badly. One wrong field coil out of four amounts to about the same thing as lifting off the top half of the motor and running the

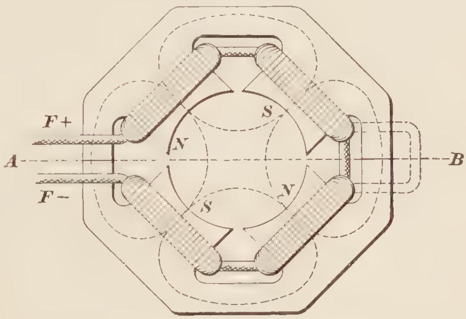


FIG. 65.

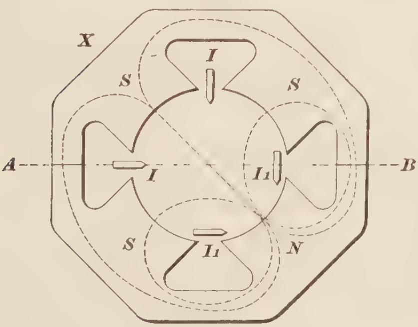


FIG. 66.

armature on the field coils in the lower half. The armature would run, but there would be great consumption of current.

90. Test for Field Connections.—If there is any doubt as to whether a set of field coils is connected properly or not, the matter can be decided by a very simple test with a piece of soft-iron rod about 3 or 4 inches long. It is well known that if a piece of iron is placed near a magnet of any kind, it will, if free to move round a center, take up a position parallel to the general direction of the lines of force that run through the place where it rests. If the person making the

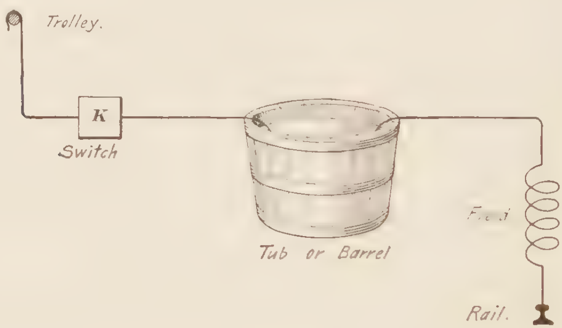


FIG. 67.

polarity test is inexperienced, it is a safe plan to take the armature out of the motor, because when a current is sent through the field coils and the pole pieces become magnetized, they induce poles of the opposite polarity in the armature core opposite them, so that unless great care is taken, the tester will not always be certain whether he is getting the effect of the pole piece or that of the induced pole in the armature core.

Procure a piece of $\frac{1}{4}$-inch iron rod and point it on one end, so that the two ends may be distinguished by feeling them. Next send a current through the fields; this can be done by using a tub or barrel of water as a resistance, connected as shown in Fig. 67. The wires going into the tub have each a fish-plate or an old bearing attached to their submerged ends. The current can be varied by varying the distance

between these pieces of metal. Sometimes it is necessary to drop a handful of common salt into the water, in order to bring down its resistance and pass a current strong enough for the test. As soon as the current is adjusted (it should not be more than the full-load current of the motor), reach into the motor and rest the blunt end of the piece of iron on the horn of one of the pole pieces and let the sharp end point towards the pole piece next to it; then pass the piece of iron on over towards the pole piece that it points at, as shown in Fig. 63. The piece of iron is held loosely at the center between the thumb and forefinger, so that it is free between certain limits to turn and follow the path of the lines of force. If the iron rod in its passage from one pole to the other tends to remain in the same general direction in which it was started, i. e., starts from one pole on its blunt end and reaches the other pole on its sharp end, showing no tendency to turn or straighten up, the path of the lines of force is correct.

Fig. 68 shows the action of the piece of iron if one of the coils is connected incorrectly. If the motor has only two coils, as shown in Fig. 63, the lines of force, when one of the coils is incorrectly connected, will take the path straight across, shown by the dotted line in Fig. 64, and the piece of iron, instead of being willing to go in the most natural way from one pole to the one next to it, will try to follow the direction shown at I_1, I_1 in Fig. 68. Of course, if the motor has only two coils, matters can be set right by reversing either of them. It does not matter whether the motor has two coils or four coils; if they are all connected properly, the path of the lines of force from one pole to another will be regular, and the piece of iron will persevere in taking up between each pair of adjacent poles the position shown at I, I, Fig. 68.

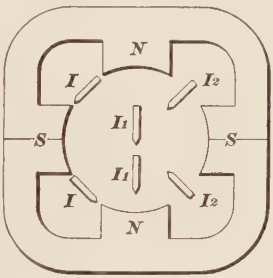


FIG. 68.

Now, suppose the motor to be of the four-coil, four-pole

type, such as shown in Fig. 65, and suppose the left-hand top field coil to be wrongly connected, so that the path of the lines of force becomes that shown by the dotted lines in Fig. 66. In this case, the test iron will rest in positions I, I on both sides of the faulty coil, because the general direction of the lines of force is at right angles to what it should be. Between the right-hand bottom coil and the two adjacent coils, the path of the lines is correct and the test iron takes up the correct position, as shown at I_1 and I_1. If, then, one of the four coils on any four-coil motor is wrongly connected, the action of the test iron will be irregular on both sides of that coil. Further than this, the pole piece coming out of the faulty coil will be weaker than any other pole piece in the motor; also, the removed corners of neighboring pole pieces will be considerably stronger than the corners adjacent to the faulty pole piece.

91. Field Connecting.—In the practical work of connecting up a set of field coils, one does not care whether the coil is connected so that it makes the pole piece a north pole or a south pole; what one must see to is that if any given pole is a north pole, the pole next to it on either side must be a south pole, and *vice versa*. Now, whether a pole will be north or south depends on the direction in which the current flows around it. This in turn depends on how the coil is wound, how the leads are brought out after it is wound, and, lastly, on how the coil is connected when it is in the motor. As we have to do only with the completed coil in the motor, we will assume that all the coils are wound alike and that in every case the inside and outside ends of the winding go to the same lugs or leads, respectively. If the current enters a coil by way of the inside end, the coil will give the pole piece one polarity, and if it enters at the outside end of a similarly placed coil, the polarity of that pole piece would be reversed. In order to make adjacent pole pieces have opposite polarity, the current must enter the coil of one at its inside end and the coil of the other at its outside end.

Fig. 69 shows four coils laid out in the same order in which they would go into a motor and connected so that

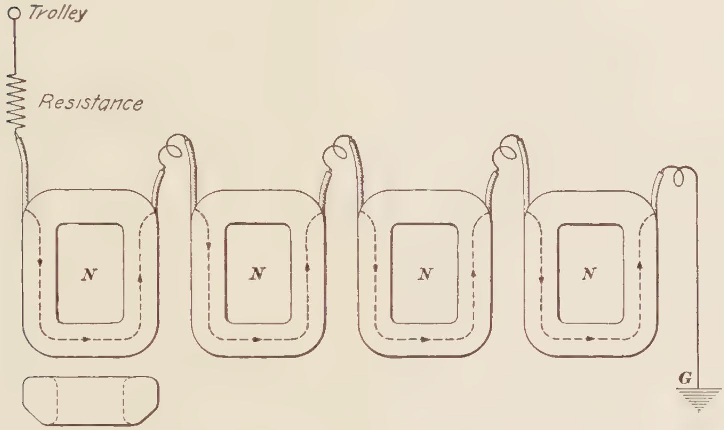


FIG. 69.

the current flows through all of them in the same direction. Fig. 70 shows them connected as they should be. In Fig. 69, it will be noticed that each of the four coils has

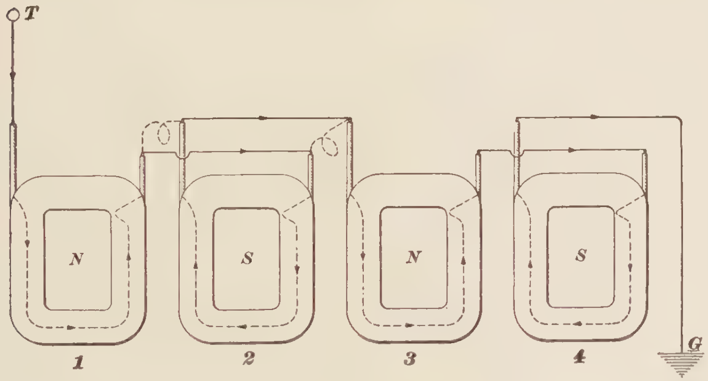


FIG. 70.

one long lead and one short one; so that if connected as shown in Fig. 69, the coils will all have the same polarity, because in each case the current goes into the coil by way

of the long lead and comes out by way of the short one, circulating through all the coils in a counter-clockwise direction.

There are two points that must be especially noted about the four field coils and their connections in Fig. 70; one is that the difference in the length of the leads enables one to tell readily which are the like ends of several coils. The next point to note is that the like ends of coils that are next to each other join together; a short lead always connects to a short lead and a long lead to a long lead. One more point to be noticed is that, after all the internal motor-field connections are made, the two field leads that are left unconnected to go to the field car wires should be alike; in Fig. 70, two long leads are left open, so that the connections must be correct. In Fig. 69, one long lead and one short lead are left open, so that the connections are not correct. It is, however, possible to get the coils connected improperly and still have two like ends left open; Fig. 70 shows one way in which this might be done if the second coil were connected as indicated by the dotted lines instead of by the full lines. The connections should be carefully made and well taped up, because they are in very close quarters and are liable to chafe.

92. Coils With Leads on Opposite Ends.—Fig. 71 shows a type of coil that is very easily placed incorrectly. Fig. 72 is the same style of coil except that it has leads instead of lugs. It does not make any difference which way the coil is turned; it looks just the same. To add to the possibility of confusion, the coil has the same shape on the bottom as on the top, as shown in Fig. 71 (*b*), so that it is an easy matter to get the coil into the motor top side down. The effect of getting such a coil in end for end, or top side down, can be seen by the aid of Fig. 72. In this figure, TT is supposed to be the wire that takes the current to the coil; if this wire is connected to the coil as it stands in the figure, the current goes into the coil by way of the $F+$ lead, which we will call the *inside end;* if the coil

be now turned over so that the *a* side comes where the *b* side is, and *vice versa*, the *F*— lead is brought nearest the

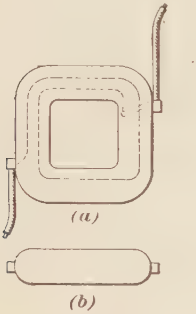


FIG. 71.

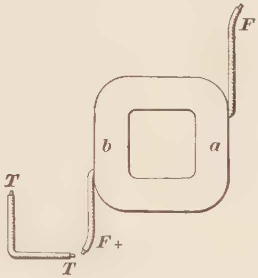


FIG. 72.

wire *T T*, and if it is connected to it, the current enters the coil by way of the outside end and reverses its polarity.

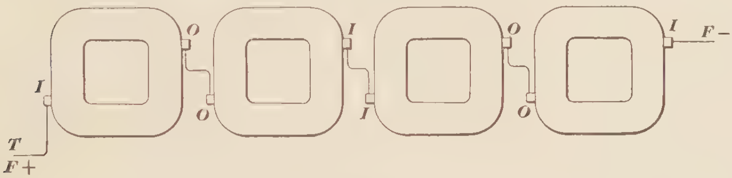


FIG. 73.

Fig. 73 shows how such a set of coils appear if they are connected correctly, and Fig. 74 shows the effect of having one coil in top side down. Observe that in Fig. 73 the *I*'s

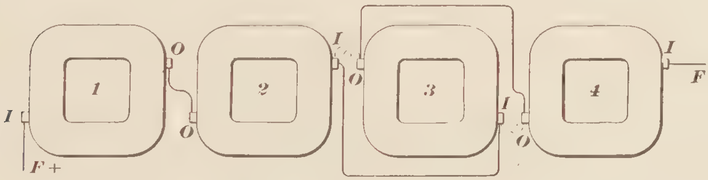


FIG. 74.

connect to *I*'s and the *O*'s to *O*'s; also, that every other coil is turned end for end; this is done in order to bring together those lugs that connect together, thus avoiding a long connecting wire, which would have to be cleated up to keep it

away from the armature. If coil *3* were connected as indicated by the dotted lines in Fig. 74, the polarity of the coil would be reversed.

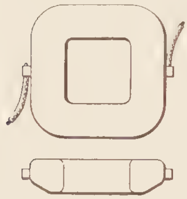


FIG. 75.

Fig. 75 shows a type of coil with the lugs on the side and midway between the two ends. This coil is convex on the bottom and cannot be put in top side down. As the lugs are midway between the ends of the coil, it is an easy matter to get the coil in end for end. The correct connections for coils of this kind are shown in Fig. 76. The connection between coils is

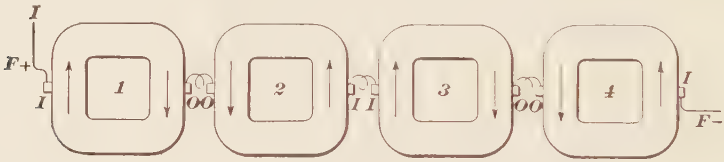


FIG. 76.

short and is not very apt to give trouble from getting loose.

ELECTRIC RAILWAYS.

(PART 6.)

CAR APPLIANCES.

1. Trunk Wiring.—Fig. 1 indicates the trunk wiring of an ordinary car and shows those devices, outside of the motors and controllers, that are necessary for the operation

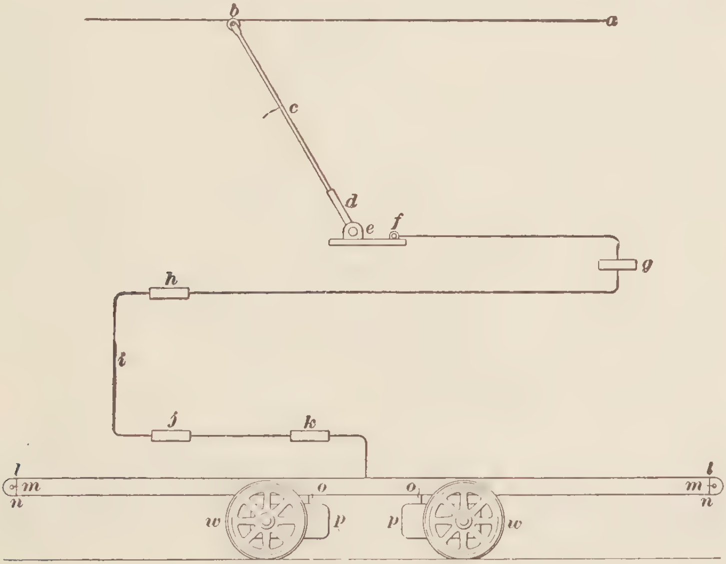


FIG. 1.

of the car. The appliances used for heating and lighting are not indicated. The trolley wheel b is held in a *harp* that is mounted on one end of the trolley pole c. The other end

For notice of copyright, see page immediately following the title page.

of the pole fits into the *socket d* on the *trolley base e*. One end of the trunk wiring attaches to the trolley base at *f* and after passing through the two hood switches *g*, *h* and the fuse box *j*, splices on to the wire *l l* running to the trolley posts in the two controllers. In some cases, the current also passes through the lightning arrester *k*, though usually the arrester is simply tapped on to the main trolley wire.

TROLLEY POLE AND FITTINGS.

2. The Pole. — The *pole* proper, which is from 12 to 15 feet long, is about 1½ inches in diameter at the large end, and holds this diameter for about 2 feet of its length, when it begins to taper and gradually draws down to a diameter of 1 inch. Most poles are steel, hard drawn by a special patented process, and offer great resistance to bending. A slight bend in a pole is generally straightened by using a post with a hole in it as a vise and bending by hand; but severe bends should be taken out by sledging cold. A pole should not be heated to straighten it, as the character of the

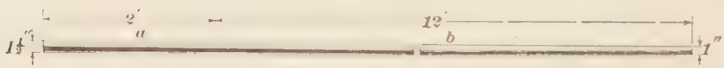


FIG. 2.

steel is such that the part heated becomes soft and easily bent. The poles generally used cost from $1.50 to $2.00, according to the length and quality. Fig. 2 gives an idea of the straight and tapered part of a standard pole.

3. The Ferrule.—As a rule, each pole is provided with a *ferrule*, which is designed to receive the trolley rope, and which consists of a brass or malleable-iron ring with an eye in it to take one end of the rope. It is secured to the small end of the trolley pole,

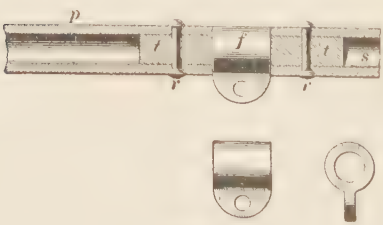


FIG. 3.

as shown in Fig. 3, where *p* is one end of the pole, *f* is the ferrule, and *s* is one end of the harp stem; *t t* is a pin passing into the pole and stem through the ferrule. This pin fits the ferrule loosely, so that the latter may be free to turn when the pole is swung around, but it is forced into the pole and harp stem and is riveted by means of rivets *r*, *r*. A ferrule is not used on all roads, its place being taken by an eye cast in a projection on the harp itself, as shown at *e*, in Fig. 4. In either case, the eyehole should be well rounded out to avoid cutting the rope, a thing that happens very often and causes much inconvenience. Fig. 4 also shows the manner of attaching the harp directly to the pole. In this figure, *b* is the harp; *p*, the end of the pole; and *t*, *t*, the rivets by which the two are fastened to the connecting pin.

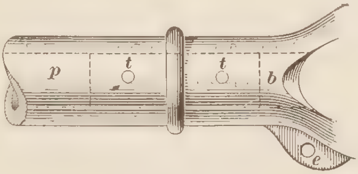


FIG. 4.

4. The **harp** is the name given to the fork that holds the trolley wheel and its axle; it also holds two contact springs *s*, *s*, Fig. 5. In this figure, *b* is the harp proper; *a*, the axle; *s*, *s*, the two springs on either side of the harp; and *c*, *c*, two cotter pins that pass through two holes drilled into the ends of the axle and serve to keep the axle in place. It has been the custom to make trolley harps of brass, but malleable iron is fast replacing it, because it is cheaper and stronger and offers less temptation to thieves. The main points that govern the selection of a harp are narrowness and smoothness; all edges should be nicely rounded off

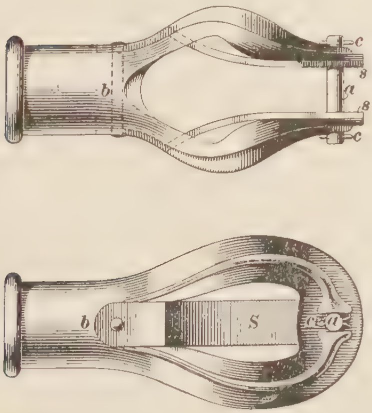


FIG. 5.

to avoid catching in the line work when the trolley wheel flies off the wire. The selection of a good harp means a great saving in poles, ropes, and overhead work.

5. The Wheel.—The trolley wheel is a device on which much experimenting has been done to determine the best shape of wheel and the best composition of metal consistent with long life of the wheel and trolley wire. Some wheels wear out sooner than others and some are harder on the trolley wire than others. A wheel that is too soft will wear out very soon; on the other hand, a wheel that is too hard or that has a poorly shaped groove will scrape the trolley wire at curves and turnouts. Almost all roads go through a certain amount of experimenting to decide what shape and

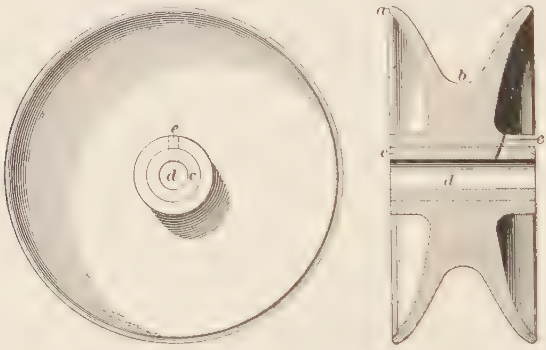


FIG. 6.

metal are best adapted to the overhead construction. A good lesson can be learned from a careful observation of worn-out wheels; some wheels wear out most in one place and some in another; the same make and shape of wheel will wear differently on different branches of the same road. If both flanges of the wheel persist in getting sharp, it indicates that the groove is too deep or too narrow, or both. If the groove wears down to one side, the indications are that the pole is in crooked or that the harp is crooked or that the trolley wire is out of center. Too

much stress cannot be laid on the importance of getting the pole so adjusted that when it is in its normal position, the trolley wire rests on the bottom of the groove and runs parallel to the flanges. Fig. 6 shows a trolley wheel; *a* is the flange; *b*, the groove; *c*, the bushing or bearing; *d*, the hole through which the axle passes; and *e*, the hole for oiling. The bushing, or bearing, is a brass spiral sleeve filled with graphite, and can be forced in or out of a wheel when wear makes it necessary to do so. The bushing is a very particular part of a wheel and should be well made; to keep a bushing in good order, it should be well oiled every fifteen or twenty miles that the car makes; for when it is taken into consideration that a trolley wheel turns around about five thousand times every time that the car runs a mile and that cars make several miles an hour, the importance of a perfect bearing is apparent. On roads that make any pretension to looking after their trolley wheels, a platform is built that overhangs the car roof, so that the wheel may be oiled. Fig. 7 indicates the kind of platform referred to. When oiling a wheel, a piece of waste should be held under it to prevent the excess of oil falling on the roof of the car, where in course of time it makes a mess. When a wheel is allowed to run dry, the hole in the bushing soon wears to an oblong shape, allowing the wheel to vibrate and emit a chattering noise. The same noise may be caused by a wheel having flat spots in the groove. These flat spots may be due to the wheels sliding along for want of oil instead of turning; in other cases, they may be due to some imperfection or they may be due to soft spots in the metal of which the wheel is made. In any case, the wheel should not be run, but should be taken out, and if there is any stock left in it turned down to be used again.

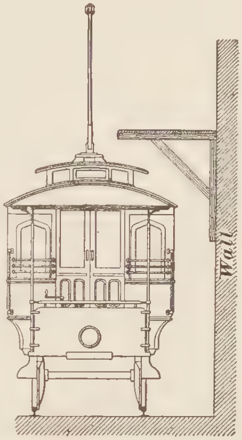


FIG. 7.

TROLLEY STANDS.

6. General Description.—The pole fits into and is held by a device called the **trolley stand,** which gives the pole freedom of motion in two directions: up and down, to enable the pole to adjust itself to stretches of wire varying in height above the ground, and sidewise, so that the pole may be swung around when the direction of motion of the car is changed and also that it can follow the wire freely in going around curves. The trolley stand has two members: the upper member, which holds the pole and is free to turn around the lower member in a horizontal plane, and the lower member, called the base, which is screwed to the board or bridge and acts as a center around which the upper member may turn; this lower member also receives the wire that leads the current from the trolley stand to the controlling devices. The upper member includes the *socket*, the *spring*, and the devices for adjusting the tension on the spring.

7. The Nuttall Trolley Stand.—Figs. 8 and 9 show one form of Nuttall stand. *G* is the socket proper and *f*, *f* two wings forming part of the socket casting provided to

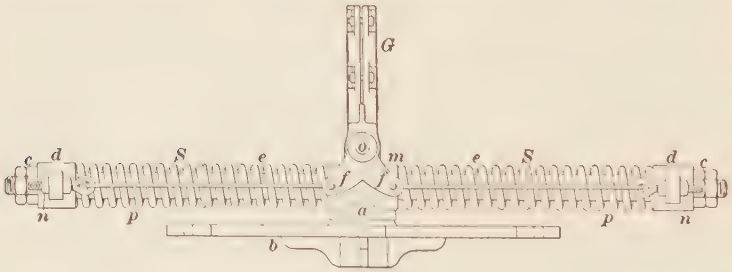


FIG. 8.

receive one end of adjusting rods *e*, *e*, the other ends of which pass through cup castings *d*, *d* to receive adjusting nuts *n*, *n*. On this form of trolley stand the pole may either be rocked over independently or it can be swung around

with the upper member m. Casting m also receives the two guide rods p, p, over which work springs S, S. When the pole is pulled one way or the other, one pair of tension rods (only one of each pair is shown in the figure) pulls on one

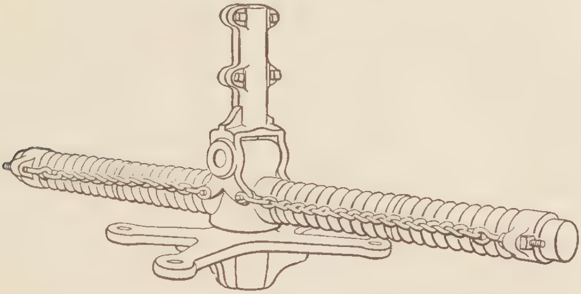


FIG. 9.

compression cup, compresses one of the springs, and produces the desired pressure of the wheel against the trolley wire. To increase the force with which the wheel is pressed against the trolley wire, tighten the nuts c, c; this will cause some slack in rods e, e, so that the nuts n, n also must be tightened. To render springs S entirely inactive, remove the

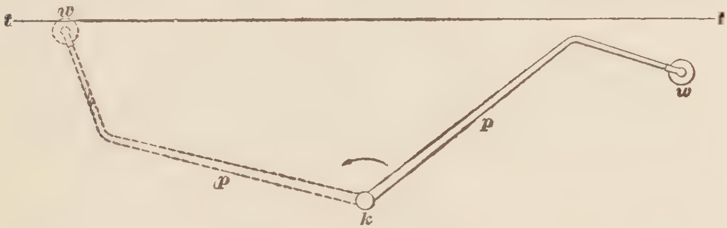


FIG. 10.

nuts n, n altogether. In the Nuttall trolley, it is possible either to swing the trolley around or to let it stand straight up and rock it over in the opposite direction. All trolley stands do not admit of this, but it is a good feature, because in case a pole is bent, as shown in Fig. 10, rocking the pole over does away with the disadvantages of the bend, whereas

swinging the pole will do no good at all. Sometimes, instead of the rods *e*, *e*, chains are used, as shown in Fig. 9.

8. The T. H. Trolley Stand.—Figs. 11 and 12 show a form of trolley stand that was formerly much used. Fig. 12 is a perspective view of the upper member of the stand. On bending the pole to the left, rocker *R* winds up the straps attached to the spring frames and pulls out the battery of springs *S*. To increase the tension, nut *n* must be tightened. It can be seen that with this style of base the trolley pole cannot be rocked over, but must be swung

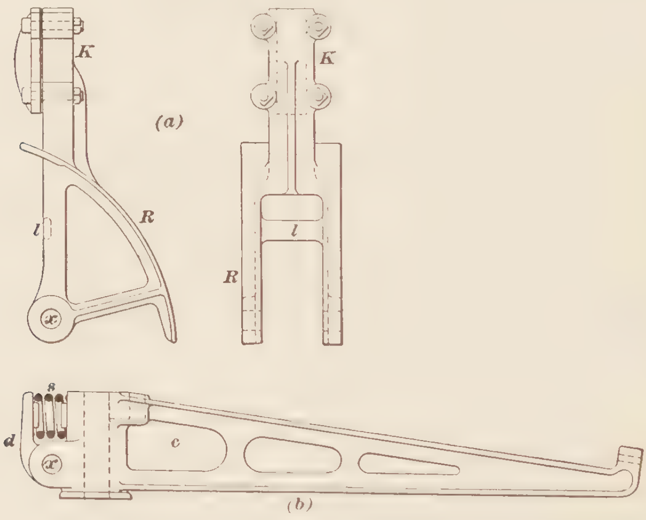


FIG. 11.

around with the upper member. In Fig. 11 (*b*), a spring *s* may be seen on the main casting *c*. There is a projection on one side of the main casting, and this projection goes into one end of the spring; an iron dog *d* that moves around the same center as the rocker casting *R* has a slight projection that goes into the other end of spring *s*. In case the trolley rope breaks or for any other reason the pole flies up, rib *l* of casting *R* compresses spring *s* and relieves the trolley

stand of the great shock it would otherwise receive. The variety of trolley bases in use is very large, but they all contain about the same essential features.

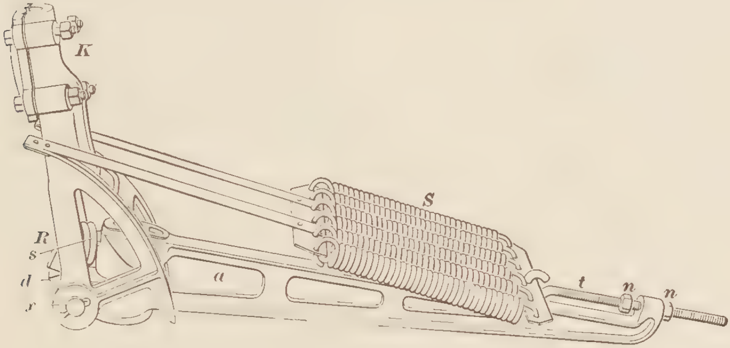


FIG. 12.

9. Pressure Between Wheel and Wire.—The pressure with which the wheel presses against the trolley wire varies from 12 to 20 pounds, according to local conditions and to the speed at which the car is to be run. If the pressure is too light, the pole will be continually jumping off the wire at every kink or turn; if the pressure is too great, it causes an unnecessary wear of the trolley wire, wheel, and axle and also makes it much more difficult to get the wheel back on the wire after it has jumped off. Under ordinary conditions, the pole should make an angle of about 45° with the roof, or deck, of the car, and a pressure of about 15 pounds between the wheel and the wire will usually give good results.

CANOPY SWITCHES.

10. General Description.—The canopy switch, also called the hood switch, bonnet switch, overhead switch, or main-motor switch, is a device that is placed just above the motorman's head on the under side of the bonnet. It is preferably placed a little in front of the motorman's position, so that he can look up and see it without turning his head

around. The object of this switch is to provide a certain and simple means of cutting off the main-motor current, in case anything should happen to one of the controllers to make that device useless for throwing off the power. Sometimes a controller becomes grounded or short-circuited, and the consequent flow of current through it is so great that the controller cannot break it; again, sometimes the trouble with the controller or some other device is such that it is very convenient to put the controller on the first or second notch and to start, run, and stop the car by means of the canopy switch. This switch is also used to entirely cut the wiring and all the devices out of communication with the trolley wire when it is desired to inspect or work on any of the controlling devices. A motorman should never try to adjust a controller finger or to replace a broken motor brush without first throwing the canopy switch handle to the off-position.

11. Westinghouse Canopy Switch.—Fig. 13 shows the general appearance of the Westinghouse switch. The switch fixtures are mounted on a wooden base and over the whole is fitted the iron cover provided with four legs, by means of

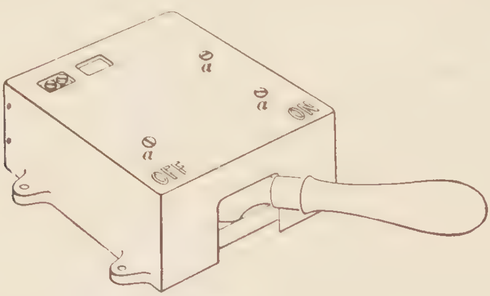


FIG. 13.

which the switch can be fastened to a wooden baseboard screwed to the under side of the bonnet. The iron cover can be taken off by taking out the three screws *a*, *a*, *a*, exposing the inside to view. These switches are sometimes called upon to break currents from 200 to 300 amperes, and

some special provision must be made for doing this without too much arcing. In the Westinghouse canopy switch this is accomplished by having the switch blade break the current in two places at once, the two breaks being separated from each other. Figs. 14 and 15 show the construction of the Westinghouse switch blade and the path of the current when the switch is closed. In Fig. 14, *h* is a wooden or rubber handle; *y* is an open-shaped piece of brass terminating in legs *f*, *f* that receive the contact tips *t*, *t*. In Fig. 15, *e*+ is the wire leading into the switch, *e*— the wire leading out of it; *a* and *c* are spring blades set into brass lugs *l*, *l*, separated from each other by the block of insulating material *d*. When the switch is closed, as shown in this figure, contact tips *t*, *t* press into blades *a*, *c*, and the path of the current through the switch is *e*+ –*l*–*a*–*b*–*c*–*l*–*e*—.

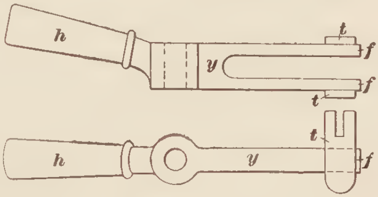


FIG. 14.

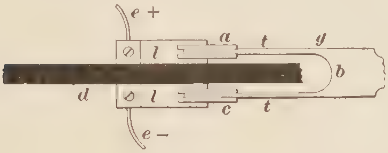


FIG. 15.

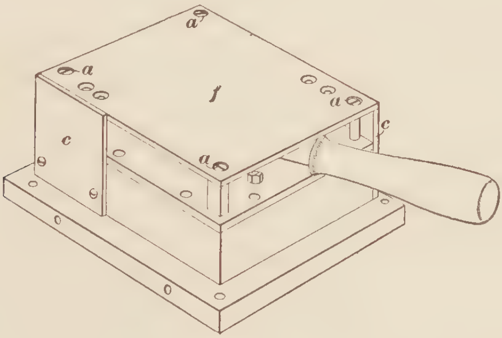


FIG. 16.

12. The General Electric Canopy Switch.—Fig. 16 shows one type of General Electric switch; the interior of this switch is readily exposed to view by removing the four

corner screws *a*, *a*, *a*, *a* that secure the fiber top piece *f*. The fiber corner pieces *c*, *c* prevent the flash licking out and disfiguring the car roof, should the switch get a little out of order. This switch is provided with a magnetic blow-out to extinguish the arc; on this account, the switch blade is made of iron, because it carries the magnetism much better than brass or copper. Fig. 17 gives the general idea of how

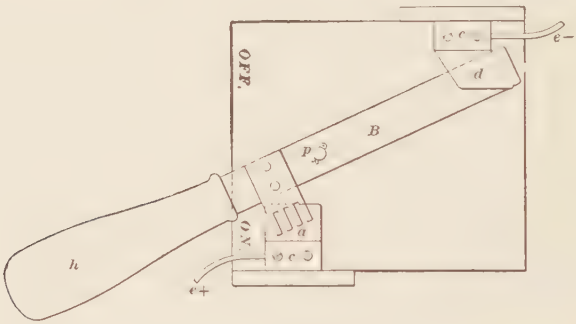


FIG. 17.

the switch mountings appear when the fiber top *f* is removed. *B* is the switch blade provided with handle *h*, working around a center *p*; *c*, *c* are brass castings provided with holes to receive wires *e*+ and *e*−, and also provided with spring blades *a*, *d*, into which the switch blade presses when the switch is on. When the switch is on, as shown in the figure, the path of the current is *e*+–*c*–*a*–*B*–*d*–*c*–*e*−.

13. Fig. 18 illustrates the principle on which the blow-out coil works. *m* and *n* are two pieces of iron; *m* has a handle *h* and is movable around a center; *n* is stationary and has wound upon it a coil of wire that carries the main-motor current; one end of this coil is attached to *n* and the other end of the coil goes to one of

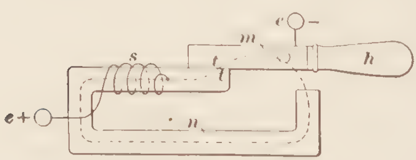


FIG. 18.

the connecting posts $e+$; m is connected to the other binding post $e-$. In the figure, the switch is shown closed; current is therefore passing through it, and the blow-out coil s causes magnetism to pass through the path indicated by the dotted line. As soon as the switch is open, the circuit is broken at t, t and the lines of force flowing across this point break the arc formed there. When the switch is opened, the magnetic and electric circuits are broken in the same place t, t and the magnetic field promptly extinguishes the arc. A switch adapted for use on a 500-volt circuit will not be reliable on a 1,000-volt circuit; nor will switches designed for motors of a certain horsepower work satisfactorily very long on a car equipped with motors of much greater horsepower, because the greater current causes so much more heating that the insulation on the magnetizing, or blow-out, coil gets roasted and becomes carbonized. When this happens, the current, instead of passing around the turns of wire and magnetizing the core, short-circuits through the burned insulation and produces little or no magnetism.

FUSE BOXES.

14. Use of Fuse Box.—It has been seen that the hood switch is a safety device and that it must be operated in case of an emergency by the motorman. The fuse box is also a safety device, but it is automatic in its action. If no fuse box is put on a car, the first time that a ground occurs on a motor or any of its controlling devices, the rush of current is very great and the weakest part of the circuit, that is, the part of least current-carrying capacity, will give way. This weak part may prove to be a loose connection in the car wiring or a bad contact in the controller; but it is more than likely that the weak spot will show up inside a motor, where the damage costs most to repair. The idea of the fuse box is to provide a weak part in the circuit: in case of an abnormal rush of current, the fuse

in the fuse box should, therefore, blow before anything else gives way. To make sure that it will do so, the fuse wire is made smaller than any wire found in any of the devices or car wiring that are called on to carry the main current.

SIZE OF FUSE.

15. Factors Determining Dimensions of Fuses.—On a 30-horsepower equipment the armatures are generally wound with about a No. 9 B. & S. wire and the fields with about a No. 4 B. & S. or a No. 5 B. & S. wire, according to the nature of the work that the motor is called on to do. It would appear that in the selection of a fuse wire, it would only be necessary to choose a wire one size smaller than that in the field winding, but for several reasons, this is not so. The fuse wire must be a great deal smaller than the field wire. In the first place, the fuse wire is not embedded in insulation, and in the second place it is not running inside a closed motor, where it can be acted on by other heating influences than the actual current flowing through it. The result of its being outside, in an exposed place, is to give it plenty of air, hence facility to cool, so that for a given current its temperature will not rise as high as that of the wires inside of the motors.

16. Copper Fuses for 30-Horsepower Equipment.—As a result of experience, the copper wire used on a 30-horsepower equipment is about a No. 14 B. & S. A 30-horsepower motor running at full load takes a current of 45 amperes; two motors would, therefore, take a current of 90 amperes at 500 volts and the fuse wire would have to stand this current continuously if the motors always ran at full load. As a matter of fact, a 30-horsepower equipment running under the most usual conditions takes just about one-third of this current, or 30 amperes. Of course, there are times and conditions when the car will take more than 90 amperes, but

these do not last long, and if they do, it goes to prove that larger motors are needed for the work, for no 30-horsepower railway motor will bear up under the strain of continual full load.

17. Copper Fuses for 50-Horsepower Equipment.—A 50-horsepower motor under full load at 500 volts calls for a current of about 75 amperes and a fuse wire proportionately larger than that used on a 30-horsepower equipment. The fuse wire should be about a No. 12 B. & S. gauge. The armature of a 50-horsepower street-car motor is wound with about a No. 7 B. & S. copper wire and the field with about a No. 2 B. & S.; so a No. 12 fuse wire gives plenty of margin. In the above it has been assumed that copper wire is to be used in all cases, because there is nothing special about it. It is cheaper than other special fuse wires and is just as reliable.

STYLES OF FUSE BOXES.

18. The Westinghouse Fuse Box.—Fig. 19 shows a perspective view of a Westinghouse car fuse box and Figs. 20 and 21 show how the removable block that takes the fuse wire is constructed.

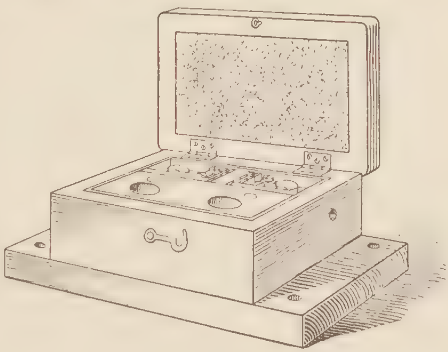


FIG. 19.

Fig. 20 shows the fuse box with the lid open; *a*, *a* are the two castings that receive the two ends of the trunk wiring through holes *d*, *d*; they are provided with switch blades to take the tongues *t*, *t* in Fig. 21. The box and also part *b* of the cover is lined with asbestos, so that the blowing of

the fuse will not set the wooden case on fire. Holes *e*, *e* give the hot air and gases a chance to escape, so that when a fuse blows, the lid of the box may not be blown off. Holes *k* are for the screws that hold the fuse box up against the platform stem under the car.

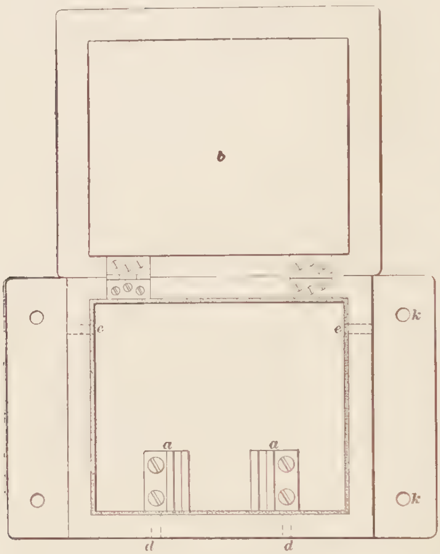


FIG. 20.

Fig. 21 shows the removable block to which the fuse wire is attached, as indicated by the dotted line; *b*, *b* are the two thumbscrews by means of which the ends of the fuse wire are secured; *c*, *c* are two finger holes used to withdraw the block when it is necessary to put in a fuse. This fuse box has the great advantage that a fuse can be put in without any danger of getting a shock, even though the trolley pole may be left on and both canopy switches closed. This figure shows the fuse wire loose, in order that it may be more easily seen; however, the three sides *o*, *s*, *p* have a groove cut in them, and the wire is drawn into this groove.

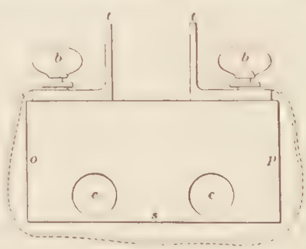


FIG. 21.

19. The General Electric Fuse Box.—Figs. 22 and 23 show one form of General Electric fuse box that is very much used. In Fig. 22, *a*, *a* are two holes through which the trunk wire passes into and out of the fuse box; on each end of the box is a hole *b*, through which a screwdriver

may be put to loosen or tighten screws *b*, *b*, shown in Fig. 23 (*a*); *c* is a rawhide flap that serves as a weather protector. A substantial lid is unnecessary on this fuse box, because the presence of a magnetic blow-out coil *d*, Fig. 23 (*a*), allows very little arcing when a fuse blows. Fig. 23 (*a*) shows the member that fits into the wooden case shown in Fig. 22; *a*, *a* are two lugs provided with holes *e*, *e* to take the ends of the trunk wire and screws *b*, *b* to secure the wire in place; *c*, *c* are also two lugs provided with thumbscrews to take such a special fuse wire as is shown in Fig. 23 (*b*). This special fuse with terminals and made of regular fuse wire is not necessary, as almost any fuse wire can be secured under the thumbscrews, but it is a good thing because it makes sure that in a majority of

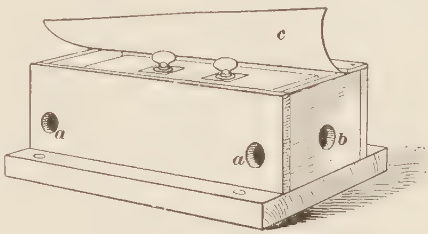


FIG. 22.

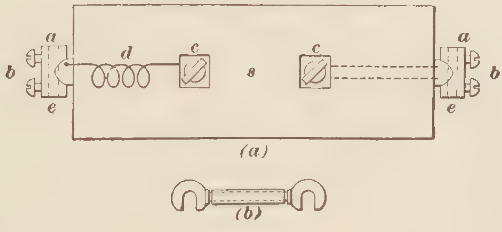


FIG. 23.

cases the car is provided with a fuse of the proper size. On one side, *a* and *c*, Fig. 23 (*a*), are connected directly together, but on the other side they are connected through coil *d*, which has an iron core so disposed as to throw a strong magnetic field across the space *s*, where the fuse blows. This fuse box does good work when in good order and will only give trouble when continuous abuse causes the blow-out coil to become short-circuited.

CIRCUIT-BREAKERS.

20. Circuit-breakers have been used for a number of years in street-railway power houses, but their use on street cars is of comparatively recent date. The circuit-breaker, as its name implies, is a device for opening the circuit between the trolley and ground whenever the current, for any reason, becomes excessive. On a street car they occupy the position usually taken by the hood switches; in fact, they are practically an automatic hood switch, and therefore serve the combined purpose of hood switch and fuse box. Fuses are always more or less unreliable. Sometimes they blow when they should and sometimes they do not. The circuit-breaker is essentially a switch that is held closed against the action of a spring by a catch or trip attached to the armature of an electromagnet. The current from the trolley passes through the coil that forms the electromagnet, and if for any reason the current becomes excessive, the armature is attracted, thus releasing the catch and allowing the switch to fly open. The circuit-breaker does not, therefore, depend on any heating action for its operation, and hence works almost instantaneously and with much more reliability than a fuse.

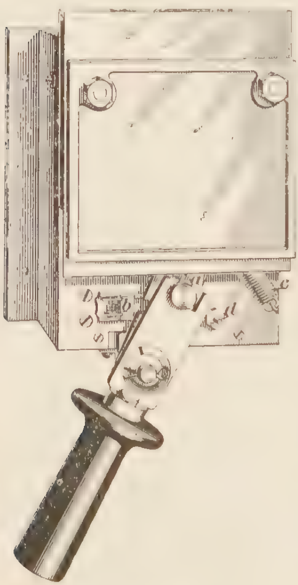


FIG. 24.

Circuit-breakers used on cars are generally arranged so that the arc formed at the break takes place in a magnetic field and is thus blown out in the same way as in a controller. Fig. 24 shows a car circuit-breaker. In general appearance it is much like a hood switch; *a* is the switch blade and *b* is the catch that holds it in position against the action of the spring *c* when the breaker is set. A blow-out coil is contained in the box, and this forms a magnetic field by

which the arc is extinguished. The nut d is used to adjust the current at which the breaker trips, by varying the tension on a spring against which the armature has to pull.

21. Fig. 25 shows another circuit-breaker of larger capacity. This type is also used on cars equipped with heavy motors. When so used, it is in many cases mounted in a box with the handle h projecting at one end. A and K are the terminals of the breaker and B is the tripping coil, which also serves to set up the magnetic field necessary for blowing out the arc. X is the armature of coil B and is pulled down against the action of the spring S whenever the current exceeds that for which the breaker is set. The tripping current is adjusted by means of nut T. The iron plate P and a similar one back of it are magnetized by the current in coil B, and as the break takes place between these two poles, the arc is promptly extinguished by the field that exists there. Fig. 26 will give an idea as to the principle of operation. A and K are the terminals, d d is a contact that is forced up against F, F when the breaker is set. The current then takes the path A–B–F–d d–F–K. When the breaker trips, the contact piece d d flies down and the tendency is for an arc to form between F, F; the magnetic field blows the arc upwards, and whatever burning takes place is on the contacts E, E, which are so constructed that they may be readily renewed. When it is desired to trip the breaker by hand, the knob N, Fig. 25, is pressed.

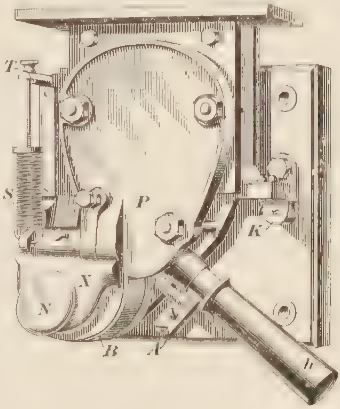


FIG. 25.

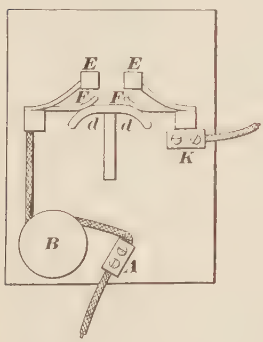


FIG. 26.

STREET-CAR LIGHTNING ARRESTERS.

22. Each car should be equipped with a lightning arrester and in some cases, on the larger cars, two arresters are provided. The arresters used on cars do not differ materially from those used for other work and which have been described previously. The arresters made by the General Electric Company are of the magnetic blow-out type and are mounted in a porcelain case. The Westinghouse car arrester extinguishes the arc that would otherwise follow the discharge by confining it between two lignum-vitæ blocks, where it is smothered out. A lightning arrester used on street-railway service is used under especially severe conditions, because every discharge to ground gives rise to a short circuit, since one side of the system is grounded. The arresters should be inspected from time to time to see that their air gaps are in good order.

23. Westinghouse Arresters.—Fig. 27 shows the Westinghouse car lightning arrester; (*a*) shows the arrester with the iron cover on and (*b*) with the cover off. The

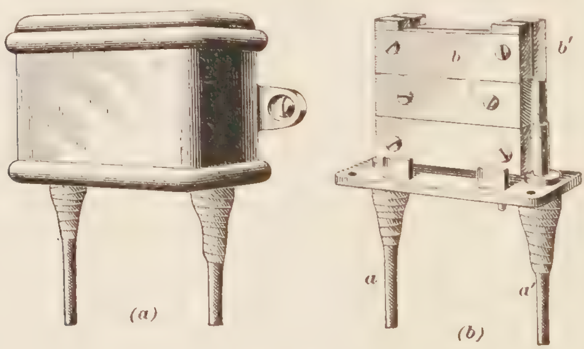


FIG. 27.

wires *a*, *a'* pass through the bottom and connect to the terminals, which are clamped between the blocks *b*, *b'*. These terminals are separated a short distance, and the space between them is bridged over by a number of charred

grooves, across which the discharge leaps. Fig. 28 shows the arrester as mounted on a car in connection with a choke coil. The ordinary choke coil used on street cars consists of 10 or 12 turns of wire wound on a wooden core about 2 inches in diameter. The coil shown in Fig. 28 is wound on a grooved wooden core and bare wire is used. A

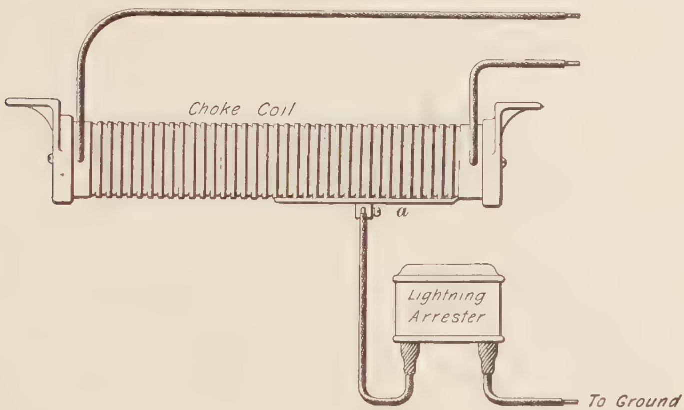


FIG. 28.

copper strap is connected to the line terminal of the arrester and is placed in close proximity to the turns of wire. When a discharge comes in over the line, it can jump from any of the convolutions to the strap and thus pass off through the arrester to the ground. In the great majority of cases, however, the plain choke coil is used.

24. Inspection of Lightning Arresters.—All lightning arresters of whatever make should be inspected after each thunder shower, for even if the arresters themselves are in good shape, there may be some loose or broken connection in a wire leading to or from the arrester. If the ground wire is broken or disconnected, the arrester might just as well not be on the car at all.

The principal point to be observed about an arrester is that the air gap should be thinner or more easily punctured than any of the insulation to be found on the motors or the

controllers. If inspection is neglected and, through the burning and jolting of the car, the air gap is allowed to get thicker than the insulation it is to protect, the lightning will jump through the insulation, rather than jump across the air gap.

25. Connections for General Electric Arrester.—Fig. 29 is a diagram of the General Electric Company's latest type of magnetic blow-out arrester, and shows the manner of connecting the arrester. A carbon resistance $z\,l$ is divided into two parts, r' and r; part r' is in multiple with the blow-out coil d and part r is in series with both and serves to limit the value of the trolley current that always follows the discharge across the air gap a. One end of the blow-out coil d is attached to one side of the air gap and to one end of the carbon resistance at z; the other end of the coil is attached to the carbon resistance at point p. The trolley connection enters at the upper left-hand side of the case and connects to one side of the air gap. In the figure, t is the trolley wire leading *to* the fuse box; t', the wire leading *from* the fuse box; k is the choke coil; f and a, the motor field and armature, respectively; g, the motor ground and g', the lightning-arrester ground, running from the main ground wire to a post in the lower right-hand end of the box. Ordinarily, the path of the current is t–t'–k–f–a and to the ground at g; as soon as lightning strikes, it takes the path t–t'–t''–a–n–z–p–l and to the ground at g'; on reaching point n, it has two ways of getting to point p—through the carbon resistance by way of path n–z–p and through the blow-out coil by way of path n–x–d–y–p; since the blow-out coil acts as a reactance coil, the

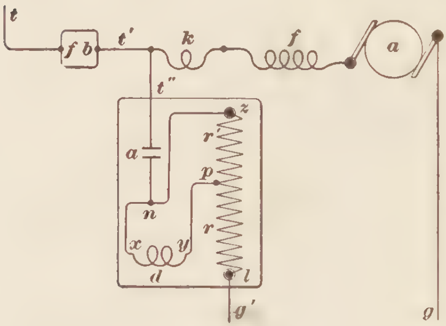


FIG. 29.

first sudden discharge prefers to take the carbon non-inductive path in multiple with it. In passing through the coil, the current sets up a strong magnetic field across the gap a; the arc is put out and the arrester is ready for the next discharge.

RESISTANCE COILS.

26. Reasons for Use of Resistance Coils.—The resistance coil, sometimes called the starting coil, is a device that is used to limit the value of the current at starting; this permits the car to be started smoothly without jerking and protects the motors from the undue strain that would result from an excessive current. It must be borne in mind that wherever there is resistance in a circuit through which a current flows, there is heat, and wherever there is heat, there is a loss of energy that cannot be converted into useful work. If it were not for this fact, the motors themselves could be so wound that they would have resistance enough to hold the current down to a safe value at starting; but then this resistance would, to a greater or less degree, be in circuit all the time and there would be a constant and excessive loss of energy due to heating. It is very often the case that cars run slower after they become well heated than they do when they make their early trips. This effect is very noticeable on heavy cars equipped with old-style motors. In order, then, that the equipment shall waste as little power as possible, the resistance of the motors is made very low; on account of this very low resistance, the line pressure of 500 volts would send through the motors an enormous starting current that would not only start the car with a jerk, but would strain the motors and gearing; to do away with these two bad effects, the starting coil is used. This coil is intended to be used only on the starting notches of the controller; when the running notches are used, the coil is entirely cut out and cannot, therefore, have any effect upon the maximum speed of the car.

27. Running Cars on Resistance Notches.—It is a very bad practice to run a car for any length of time on a resistance notch. There are three reasons for this: in the first place, it is not an economical notch on which to run, because the heating of the coil means just so much energy wasted; in the second place, the coil is designed only for the temporary use of starting, and when continuously used for slow running, it gets so hot that the insulation is destroyed, the coil is short-circuited, and the car is made to start with a jerk; in the third place, accordingly as one running notch or the other is used for running purposes, one part or the other of the coil will be abnormally heated.

28. General Electric Resistance Coil.—Fig. 30 shows a type of starting coil made by the General Electric Company. It consists of ordinary band iron folded back and forth with a ribbon of asbestos in between each fold. This iron and asbestos is built up into divisions *d* called panels, and these divisions are held in insulating bricks *a* and clamped firmly by means of the end plates *b*, *b* and bolts *c*. The whole is hung from the car floor by means of the feet *e*, *e*.

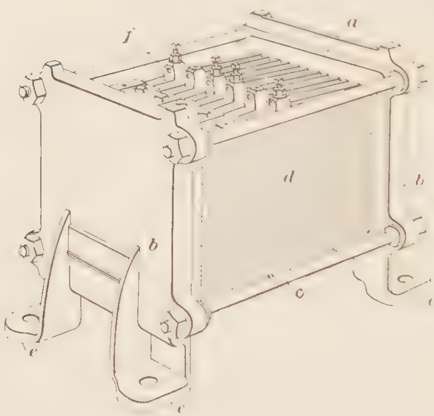


FIG. 30.

The terminals of the different sections into which the resistance is divided are connected to the binding posts *f* that receive the wires that come from the car hose and connect to the two controllers. For resistances used in connection with heavy traction work, a similar construction is followed, except that instead of a folded iron strip insulated with asbestos, a cast-iron zigzag grid is used. This makes a very substantial and well-ventilated resistance.

29. Westinghouse Resistance Coil.—In Fig. 31 is shown the type of resistance coil made by the Westinghouse Company. This coil is made of band iron insulated entirely with mica, and up to certain limits of abuse it is not affected by either heat or water. A single coil, such as that shown in the figure, is called a barrel, and the proper starting coil for any size motor can be made up of two or more of these barrels. Fig. 32 shows the method usually adopted for hanging a two-barrel starting coil. Where more barrels are required, more sets can be hung in the same manner alongside one another. In Fig. 32, *a*, *a* are two of the car sills; *b*, *b* are two strap-iron hangers through which passes a rod *d d* supporting coils *c*, *c*. Fig. 33 shows Westinghouse resistance coils mounted in an iron frame.

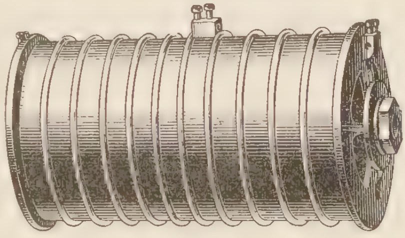


FIG. 31.

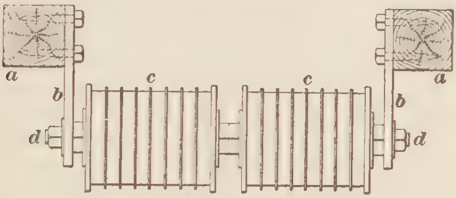


FIG. 32.

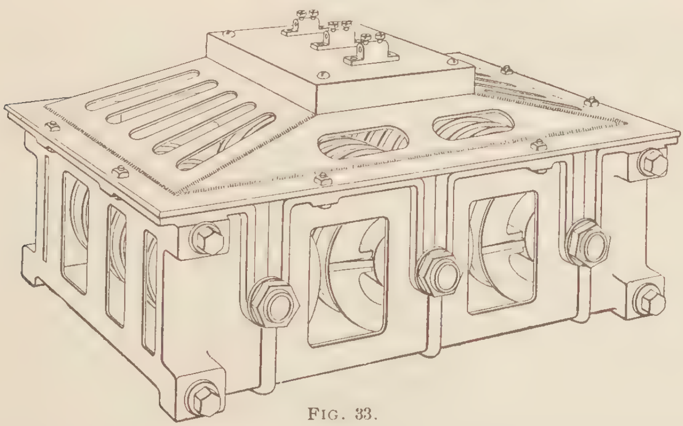


FIG. 33.

ELECTRIC CAR HEATING.

30. Introductory.—So far we have confined our attention to the uses to which electric current is put for driving the cars. Current is, however, also used for heating and lighting them, and it is necessary to consider the appliances and methods used for this purpose. It has already been explained that if a current is sent through a wire, it always encounters a certain amount of resistance and the wire becomes heated. If the power used in forcing the current through the wire is large, the temperature of the wire will be high and the wire may be brought to a red or even a white heat. When the heating effect is sufficient to bring the conductor to a white heat, light is produced, as in the case of the incandescent lamp. In ordinary line wires, there is a heating effect, but the resistance of the wire is so low that the rise in the temperature of the wire is not noticeable. When the temperature is very high, as in an incandescent lamp, it is necessary to mount the conductor or filament in a vacuum, so that there will be no oxygen present to oxidize it. In electric heaters this is not usually necessary, as the temperature at which the wire is worked under normal conditions is not high enough to cause damage.

31. General Remarks on Heater Construction.—All electric heaters are made on the same principle—that of enclosing a high-resistance wire in a case that is designed to keep the feet and clothing of passengers out of range of the hot wire. According to the size of the car and the make of the heater, 4, 6, 8, 10, 12, or even 20, heaters are required per car. For a given amount of heat required, the smaller the heater and the more of them that are used, the more evenly will the heat be distributed through the car, but the more places will thus be created where trouble is liable to arise.

As regards efficiency, heaters of all makes are about the same. To keep a 20-foot closed car comfortable during average weather in the vicinity of New York requires a

current of about 10 amperes at 500 volts. This means that between 6 and 7 horsepower is used to heat a car. It is easily seen, then, that it costs considerable to heat a car by electricity and that when the heaters are in use, there is a considerable additional load thrown on the station. On the other hand, electric heaters occupy no passenger space, they distribute the heat more uniformly than stoves, they are cleaner, and they allow the heat to be more easily regulated. For these reasons, the electric heater is extensively used, even though it is more expensive to operate than a coal stove. Electric heaters are nearly always installed in such a manner that at least three different degrees of heat may be obtained by operating a **heater switch** that changes the connections of the heaters.

The number of different makes of heaters is so large that it would be out of the question to treat all of them here. We will, however, describe one or two typical examples in order to illustrate the method of connecting. The connections for the different makes are much the same.

EXAMPLES OF ELECTRIC HEATERS.

THE JOHNS HEATER.

32. In the **Johns** system of car heating and in most other systems, the heaters are distributed through the car. In cars in which the seats run lengthwise, the heaters are hung along the seat panels on both sides; in cars with cross seats, they are placed under the seats. The resistance wires of the Johns class E heaters are completely covered with asbestos thread and are then woven into a mat, the warp of which consists of asbestos cords. The heater thus formed is thoroughly impregnated with a special insulating compound baked in at a high temperature and is thus made waterproof. The heater is then attached to a backing of asbestos millboard that has been prepared in the same

way. The completed heater is put in a perforated steel casing and the electrical connections are made by means of binding posts on porcelain bases at each end of the heater.

33. Connections for Johns Heaters.—Fig. 34 gives the general outline of the Johns class E heater and also shows how the wires on the inside are brought out to the binding posts *O*, *O*, *O*, *O*; the resistance wire in the heater is in two parts that do not touch each other anywhere. In Fig. 34, *A* is the top part and *B* the bottom part; the binding posts to which they connect are set on porcelain bases *M*, which, of course, keep them apart. Wires *A*, *A* and *B*, *B* on the ends connect the heaters together on the inside of the panel, as shown in Fig. 35, which is a section of a closed-car seat with a

FIG. 34.

FIG. 35.

class E heater mounted upon it. In Fig. 35, *A* and *B* are the wires by means of which the heaters are connected together; *H* is the heater; *P*, a cross-section of the seat panel; and *S*, a space between the back of the heater and the face of the seat panel.

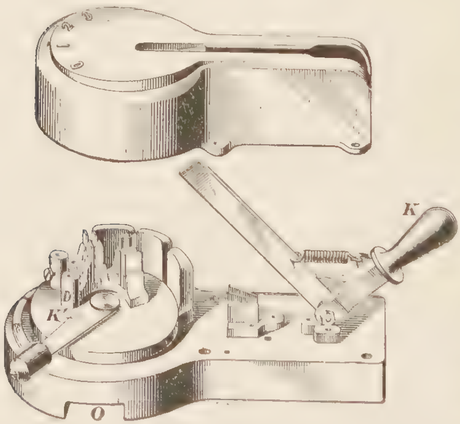


FIG. 36.

34. The Johns Regulating Switch. Fig. 36 shows the Johns heater switch. The main point about this switch is that before any change can be made in the combination in which

the heaters are running, the main heater circuit must be opened. In Fig. 36, switch K opens and closes the heater circuit and blade K' makes the combinations corresponding to the several marked notches indicated by the dotted lines on the heater case in Fig. 37. By such an arrangement, all tendency to blister and burn is confined to a quick-break

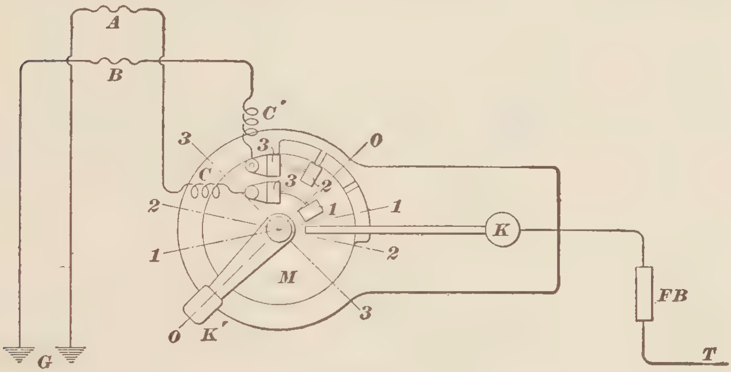


FIG. 37.

knife switch that will not be damaged to any extent by it. As long as the knife switch is open, the current is off and the regulating switch K' can be moved to any of the four notches without danger of burning; but when K is closed, K' cannot be moved at all; also, unless the regulating switch is exactly on the notch, switch K cannot be closed.

35. Fig. 37 is a diagrammatic sketch of the connections of the Johns heater switch. In the figure, the switch is at

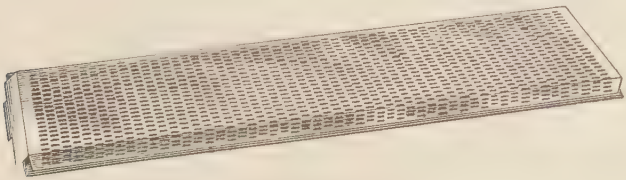


FIG. 38.

the off-, or *0–0*, position, so that no current can flow through

the circuit; when K is open and K' is turned to the first notch, indicated by the dotted line *1–1*, contact jaws *1*, *2*, and *3* swing with K' and jaw *1* falls into line with K, so that when K is closed, the path of the current is T–FB–K–*1*–*3*–C, through the top or A part of every heater, to the ground at G. When K' is moved to the second notch, jaw *2* falls into line with K and the path of the current becomes T–FB–K–*2*–*3*–C', through the B or bottom sections of all the heaters, to the ground at G. On the third notch, both jaws *3* fall into line with K and the current divides between the A and B sections of all the heaters. Jaws *3* do not touch each other, but each connects to a binding post to which the heater circuits connect. Fig. 38 is a view of the class E Johns heater, complete, ready to be put in a closed car.

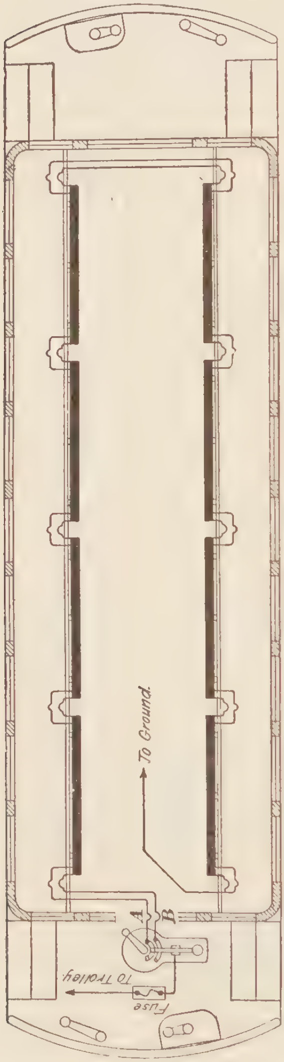


FIG. 39.

36. Car Wiring for Johns Heaters.—Fig. 39 is the car-wiring diagram for a set of class E heaters, eight to a set; the top section of each heater connects to the top section of the heater next to it, and so on all around the circuit. Care must be taken that the top and bottom wires are not confused.

THE CONSOLIDATED HEATER.

37. Construction.—Fig. 40 shows the coil used in the consolidated heater, and which is constructed as follows: On a stout iron rod are strung porcelain tubes that run the full length of the heater. These pieces have a spiral groove in them and are put on the rod so that a continuous spiral groove runs the full length of the core. The heater coil is placed in this groove. This way of arranging the coil places

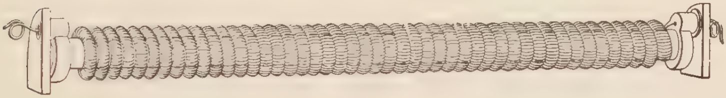


FIG. 40.

a great amount of wire in a given space and gives the air a good chance to get at all parts of it. The terminal wires that run out of the case at each end, through porcelain bushings, are attached to the ends of the coil by twisted and soldered joints and are well secured without the aid of binding posts. In each heater are two coils, like that shown in Fig. 40, placed one above the other. The top coil has the greater resistance.

38. Fig. 41 shows the type 143L heater with the front plate removed to show the two coils in place. The

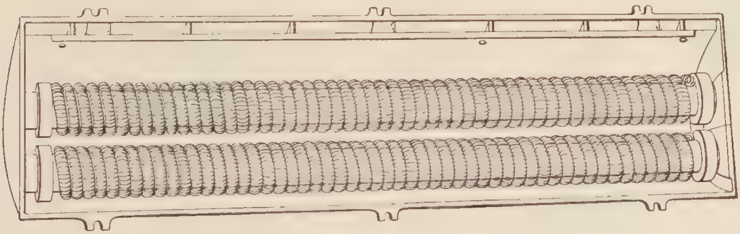


FIG. 41.

143L heater is for a side-seat closed car and is intended to be set flush with the panel of the riser.

The wiring for these heaters is carried out as shown in Fig. 42.

39. Consolidated Heater Switch.—Fig. 43 shows the heater switch with the cover on and off. This switch will handle 30 amperes at 500 volts. The spring-brass contact plates are mounted on a glazed porcelain base and the arm of the switch is of composition insulating material. The

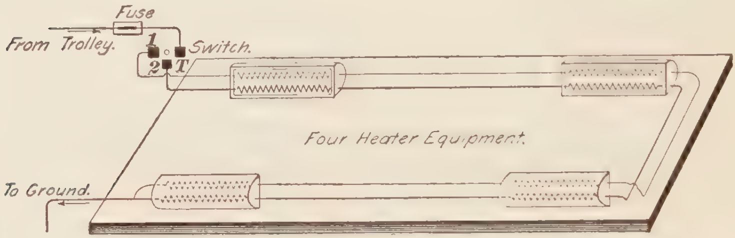


FIG. 42.

position on which the switch rests is clearly shown by a dial number that appears through a hole in the cover. In both views of Fig. 43, the switch is on the third point; on this point, the current goes in on the right-hand side of the switch at the post marked *T*. The three arms *a*, *b*, *c* are

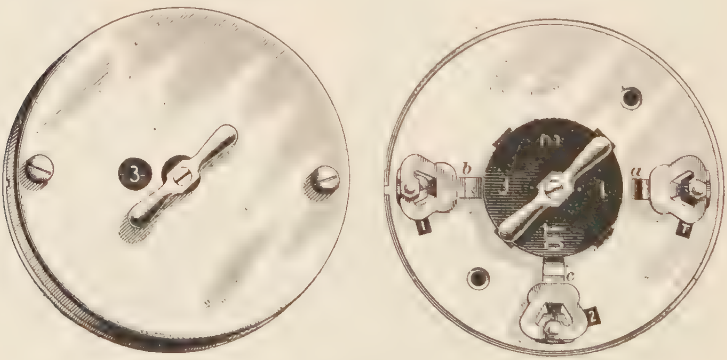


FIG. 43.

all connected together so that the current splits; part of it goes across the *b* arm to post *1* and thence to the circuit through the top part of all the heaters; the other part goes across arm *c* to post *2* and thence to the circuit through the

bottom part of all the heaters. If the handle be given a quarter-turn to the right, arm *a* leaves post *T* and goes to post *2*; arm *c* leaves post *2* and goes to post *1*; arm *b* leaves post *1* and does not go to any post at all; so post *T* is left without any connection and the switch is dead except on post *T*. If the switch is given another quarter-turn, arm *a* goes to post *1*, arm *b* goes to post *T*, and arm *c* leaves post *1*, but does not go to any post at all, so that current can only flow through the top of the heaters, which is the combination on the first point. One more quarter-turn takes arm *b* from post *T* to post *2*, arm *c* to post *T*, and arm *a* from post *1* to no post at all. On this point, then, post *1* has no connection and current flows through only the bottom part of the heaters.

40. Troubles With Heaters.—Figs. 44 and 45 show how simple mistakes may cause trouble. In Fig. 44, H, H_1, H_2, H_3 are four heaters in series across the line and the path of the current through them is T–H–H_1–H_2–H_3 to the ground at G. When connected thus, these heaters take all the current that they should have. Now, suppose that on account of some poor wiring, the wire joining heaters H_1

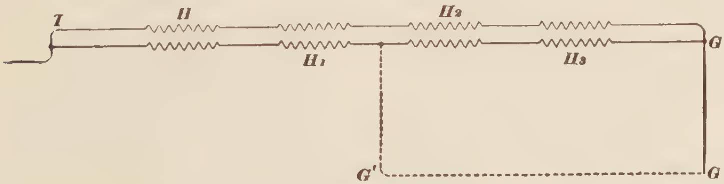


FIG. 44.

and H_2 comes into contact with a truss rod, brake rod, sand box, etc., making a ground at G'. The current goes through the top part of all the heaters the same as it did before, because that is not grounded, but the path of the current through the bottom sections becomes T–H–H_1–G'; two heaters H_2 and H_3 have their lower sections cut out entirely, and the lower sections of heaters H and H_1 are across the line alone. The result is that these sections burn out.

Fig. 45 illustrates a case of getting the top and bottom heater leads confused. The upper sketch (*a*) shows six heaters connected as they should be. In Fig. 45 (*b*), all the heaters have been connected properly except the last one, where the top and bottom leads have been crossed, with the result that the fine-wire coil in the H_5 heater is in series with the coarse-wire coils in all the other heaters, and the H_5 coarse-wire coil is in series with the fine-wire coils in

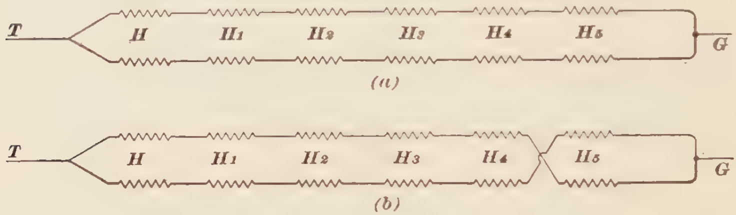


FIG. 45.

the other heaters. This is not so hard on the fine-wire coils in series with the H_5 coarse-wire, because the effect is shared by each of the five heaters ahead of the fault; but it is hard on the H_5 fine-wire coil, because the five coarse-wire coils with which it is in series pass more current than it can stand. The result is that unless the trouble is found in time, the top part of the H_5 heater will become red hot and burn out or it will melt its soldered connection.

CAR LIGHTING.

THE LAMP CIRCUIT.

41. General Remarks.—The lamp circuit is one of the most important parts of a car's equipment, and it may be of great assistance to the crew if they know how to use it. In the first place, if the lamp circuit is kept in such condition that it may always be relied on to burn when there is any power on the line, it becomes a ready means of telling if the

power is on or not. If a car refuses to move and if there is no flash in the controller when the power drum is thrown on and off, the next thing to do is to turn on the lamp switch to see if the lamps will burn; if they burn, the power is, of course, on the line, and the car's failure to move must be due to a fault in the motor circuit. Though if the lamps do not burn, it is by no means safe to draw the conclusion that no power is on the line, because their failure to burn may be due to a fault in the lamp circuit itself. The two places where such a trouble most often occurs are where the ground wire is fastened to the truck or motor and in the main light switch, if there is one, that controls all the lamp circuits. The main seat of trouble, though, is in the ground wire; never fasten the lighting ground wire to the motor or to the truck.

42. Switches for Car-Lighting Circuits.—Fig. 46 shows a type of single-pole lamp switch that is largely used. It can be used to control a single independent circuit or any number of circuits within its capacity, if all the circuits can

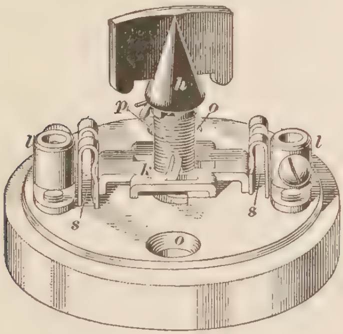


FIG. 46.

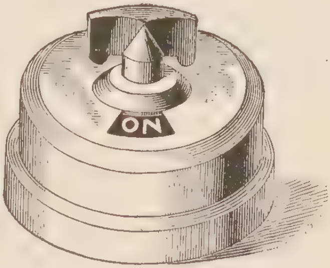


FIG. 47.

be put in multiple. The lamp wires pass under the porcelain base through two grooves made for that purpose and come up into posts *l*, *l*, where they are held by screws. When the key *h* is turned to the right, spring *p* winds up as far as possible and switch blade *k* then jumps loose from contact

tips s, s and breaks the circuit in two places. Fig. 47 shows the appearance of a switch with the cover on.

43. Fig. 48 shows an ordinary three-way switch that is commonly used on cars for cutting the headlight out and the tail-light in, or *vice versa*.

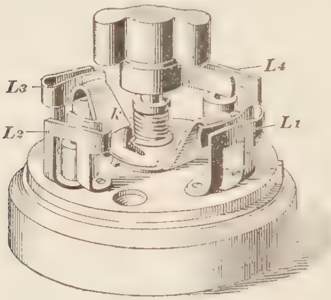


FIG. 48.

On the switch shown in Fig. 48 there are, besides the switch blade k, four spring contact clips L_1, L_2, L_3, L_4, three of which have a post to take a car wire and one of which, L_1, has no post. Inside the switch base, L_1 is connected to L_2; the trolley wire goes to the post on L_2, so that there are on the switch two trolley posts L_1 and L_2, and no matter in what position k may be, one end of it is bound to make contact with a trolley post. When k is in the position shown in the figure, the current comes in at L_2, goes over to L_1 by way of the inside connection, crosses k, and goes out on the L_3 wire. If k is given a quarter-turn, the current comes in on L_2, crosses on k, and goes out on the L_4 wire. When controlling two independent circuits or when used to cut in and out alternately two parts of the same circuit, the three-way switch has no off-position.

44. Westinghouse Plug Switch.—Fig. 49 shows the Westinghouse Company's three-way plug switch. A is a disk of hard rubber about $3\frac{1}{2}$ inches in diameter and about $1\frac{1}{4}$ inches thick. In it are three metal-lined holes T, *1*, *2*, each with a metal bottom. By means of posts not shown in the figure, one circuit is attached to the metal sheathing of hole *1* and the other to that of hole *2*; the trolley wire connects to the sheathing of hole T. B is a **U** plug with a rubber handle; holes *1*, *2*, and T have no connection with one another until plug B is shoved into place; if B is put into the two left-hand holes, the current comes in on

wire *T* and goes out on wire *1*; if *B* is put into the two right-hand holes, the current comes in on wire *T*, as before, and

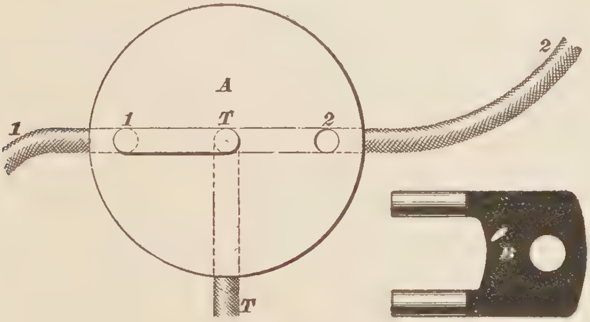


FIG. 49.

goes out on wire *2*. If plug *B* should get lost, a piece of No. 4 B. & S. rubber-covered wire bent into a **U** will answer.

CONNECTIONS FOR LAMPS.

45. Single Lamp Circuit.—The lamps used for lighting cars require from 100 to 110 volts across their terminals; hence, in order to operate these lamps on a 500-volt circuit,

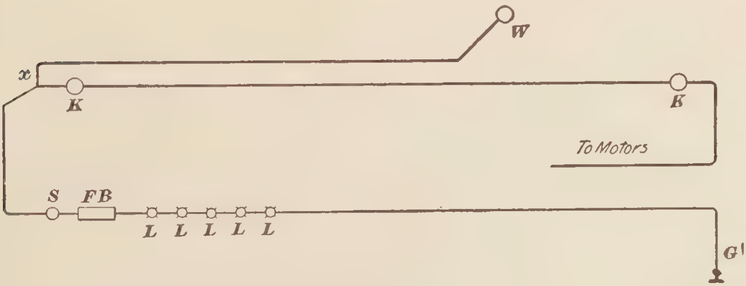


FIG. 50.

they must be arranged so that there will always be five in series between the trolley and ground. It is not practicable

to make lamps that will burn directly across 500 volts. Fig 50 shows a single five-light lamp circuit with all the lamps inside of the car; in such a case, an oil headlight or sign light must be used. The lamp circuit is tapped to the trolley roof wire ahead of both hood switches, so that the opening of either of these switches will not put out the lamps. *S* is a single-pole snap switch and *F B* the lamp fuse box.

46. Fig. 51 is the wiring diagram for a double-circuit car that has eight lamps inside, two headlights, and two tail-lights. The Westinghouse type of switch is selected on all the diagrams given here, because it is so much easier to follow the path of the current through it. When the **U** plug is in the two top holes, the headlight burns; when it is in the two bottom ones, the headlight is cut out and the tail lamp

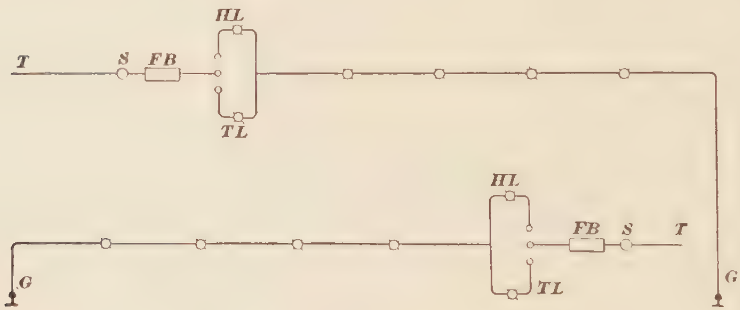


FIG. 51.

burns. *S* is the usual snap switch for cutting off the current. There is a ground wire and a trolley wire on both ends of the car, but there is no unbroken wire running the full length of the car. There is a snap switch and a three-way switch on each circuit, which may be put on the same end or on opposite ends of the car, as they are in the figure. If it is desired to control both circuits from the same end of the car, as shown in Fig. 52, two more wires must be run the full length of the car, in order to connect the three-way switch with the headlight and tail-light at the far end. The

lamps inside the car are here shown in straight rows, though they may, of course, be grouped in any desirable manner.

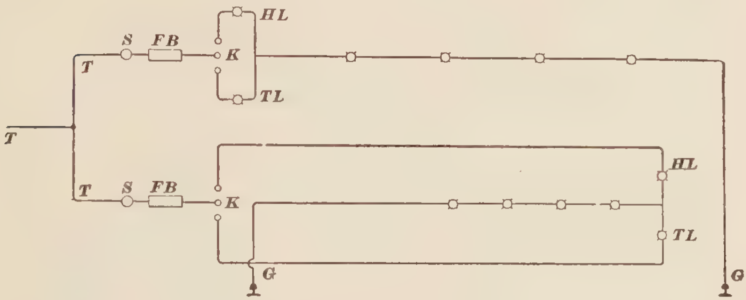


FIG. 52.

Switches K and K may be plugged so that both of the headlights or both of the tail-lights will burn.

47. Fig. 53 shows one style of lamp wiring to be used on elevated or on converted steam roads, where not only are headlights needed, but markers as well. The markers are supposed to show a red, green, or white light, or some combination of the two, to indicate the destination of the train.

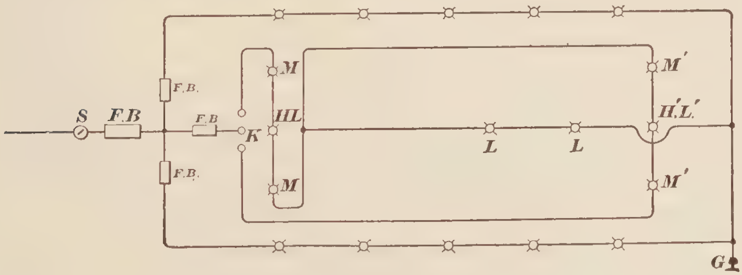


FIG. 53.

In Fig. 53, M, M and $H\ L$ are the markers and headlight on one end of the motor car; M', M' and $H'\ L'$ are the same on the other end of the car. L, L, the two lamps inside of the car, are in the form of a two-light cluster, and burn whenever the signal lamps on either end of the car burn.

DASH LIGHTS AND HOOD LIGHTS.

48. In the wiring diagrams shown, the headlights have been placed on top of the bonnets of the cars; when so placed, they are spoken of as **hood lights.** But headlights are not always put on top of the hood; on many roads, they are set into a round hole cut in the center of the dash iron; when so placed, they are spoken of as **dash lights.** Fig 54 gives a general idea as to how a headlight sets into the dash. The style shown is known as the **pot headlight.** *A* is the dash rail; *I*, the iron; *F*, the floor; *H L*, the headlight whose cover *C* swings outwards; *P*, an iron pipe, through which the wires are run to the lamp socket.

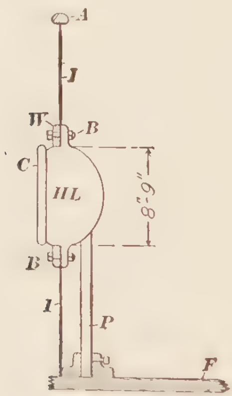


FIG. 54.

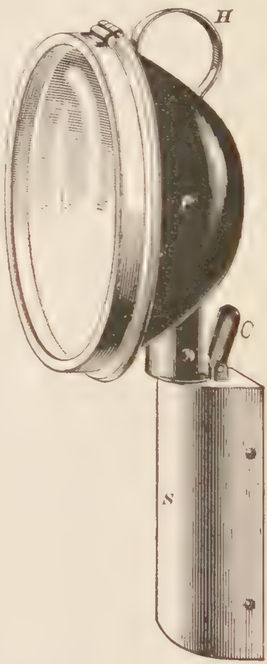


FIG. 55.

49. The dash light is not always set into a hole in the dash iron. There is one type of dash light, of which a large number are in use, that sets outside of the dash iron in a socket on the bump block. There is a socket on each end of the car and but one headlight is used on each car. When the car turns at the end of the road, the dash light, of course, stays on the same end; but if the car does not turn, the headlight must be drawn out of the socket on

one end and dropped into the socket on the other end. In Fig. 55, *P* is the changeable part of the outfit; *S* is the socket or receptacle, which is a fixture on the car, and *C* is a cap or cover that is to be shut down as soon as *P* is drawn out of *S*.

50. Changeable-Headlight Wiring Diagram.—Fig. 56 shows how two interchangeable headlights are wired in a five-lamp circuit; the headlight, of course, has a lamp *7* of its own, and according as the headlight is on one end of the car or the other, lamps L_1 or L_5 are cut out and replaced by *7*. In this figure, the headlight is in place on the right-hand end of the car and car lamp L_5 is cut out. The path of the current is T–S–$F\,B$–1–2–3–4–L_1–L_2–L_3–L_4–5–6–7–8–9–10–G. In the side of the tongue of the headlight that goes into the

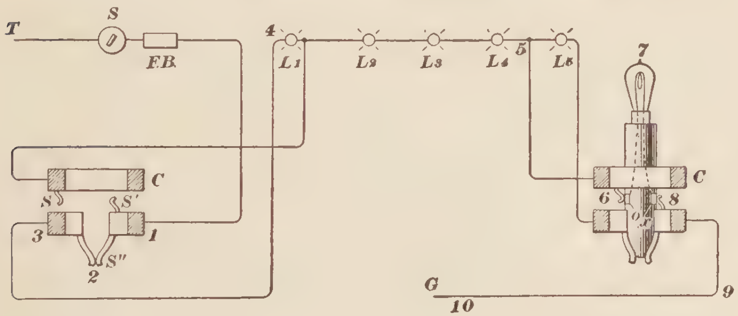


FIG. 56.

socket are two contact plates, shown at *o* and *x*, to which are connected the two wires from the posts of lamp *7*. At *S* and *S'* are shown the two springs that make contact with these two plates when the tongue is shoved into the socket. Springs *S''* make a path for the current to go through when the headlight on that end of the car is not in place. As soon as the tongue is dropped into the socket, its end forces the two springs apart and the current flows through the headlight.

51. Changeable Headlight on a Two-Circuit Car.—Fig. 57 shows a light-wiring diagram for an interchangeable

headlight to be used on a car that has two five-lamp circuits. The removal of the headlight from either end of the car

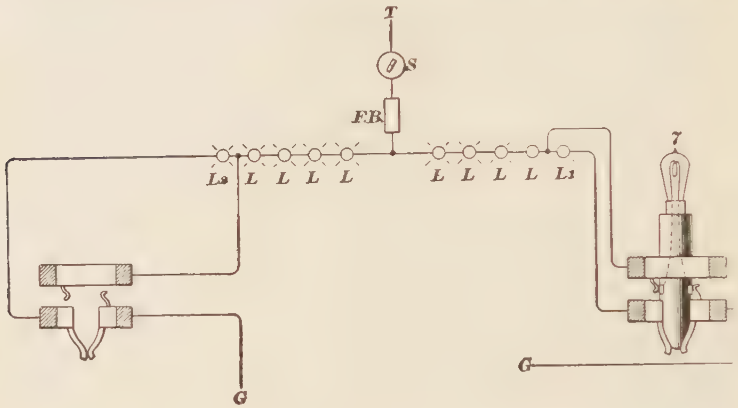


FIG. 57.

automatically cuts the fifth car lamp into circuit on that end to take its place.

BRAKES.

INTRODUCTION.

52. One of the most important items in the equipment of a car is the brake. Most of the cars in common use are equipped with **hand-brakes**, in which the brake shoes are forced against the wheels by a system of lèvers operated by the handle under the control of the motorman The general tendency has been to increase the weight and size of cars, and hand-brakes have in many cases been found inadequate to control them. This has resulted in the introduction of **air brakes**, in which the shoes are pressed against the wheels by means of a piston connected to a series of levers; this piston is operated by means of compressed air. Another type of brake which as yet has not been used very extensively is the **momentum brake**, in

which the force necessary to press the shoes against the wheels is supplied by the energy stored in the moving car.

53. On cars rigged with hand-brakes, the brake handle is the force arm of the first lever of the series of levers that press the shoes against the wheels. Fig. 58 is a sketch of the parts involved in this lever. The amount of pull on the rod depends on how much longer the brake handle is than the radius of the drum and on how much of a pull the motorman is able to exert at *P*. Suppose that the brake handle is 14 inches long. Call the diameter of the drum $1\frac{1}{2}$ inches. When a brake chain made of $\frac{3}{8}$-inch stock is wound up on this drum, the average diameter of the wrap of chain will be about $2\frac{3}{4}$ inches; one-half of this diameter, or $1\frac{3}{8}$ inches, is the short arm of the lever of which 14 inches is the long arm, making the leverage of about 10 to 1. Some men are able to pull on a brake handle much harder than others. We will assume that the average man can exert a maximum pull of 200 pounds. The pull exerted on the brake rod will then be 2,000 pounds.

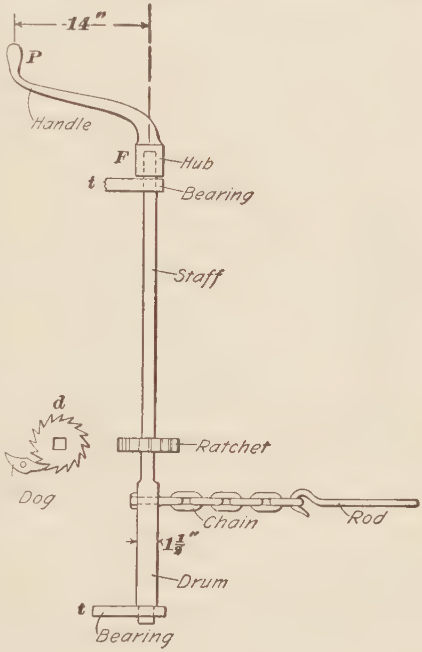


FIG. 58.

54. **Shoe Pressure.**—The amount of pressure required to brake a car depends on the weight and speed and on the number of wheels that have shoes applied to them. If a car

has eight wheels and the brakes are applied to four of them, the pressure per brake shoe must be the same as would be necessary were all the wheels supplied with shoes, because the braked wheels carry only one-half the total weight of the car; the maximum pressure to be applied to a wheel depends on how much weight the wheel supports. To avoid sliding, the pressure applied to a wheel should be a little less than the weight it supports.

55. Friction.—The amount of pressure necessary to cause a wheel to slide depends, of course, on the amount of friction between the shoe and wheel. How much of the pressure applied to a wheel is useful in stopping a car depends on the nature of the material of the shoe and wheel. Some car wheels are soft and others hard; the same is true of brake shoes. For a given hardness of wheel, a soft shoe will give more friction at a given pressure than a hard one, but it wears out sooner. Also, the amount of friction between a shoe and wheel changes with the speed of the car. The friction increases as the speed decreases, so that at high speeds a much greater pressure can be applied without sliding the wheel than at low speeds; from this it follows that in bringing a high-speed car to a stop, the brake should be eased up a little as the car slows down. Under different conditions of speed and brake shoe and wheel composition, the friction between the shoe and wheel varies from 15 to 35 per cent. of the applied pressure; that is to say, if a pressure of 10,000 pounds were applied to the shoe, only 15 per cent. of this possibly might be accounted for as retarding the car.

56. It is a well-known fact that the friction between a shoe and wheel is independent of the amount of surface exposed between them. For a given total pressure applied, the effect of varying the surface of a brake shoe is simply to vary the pressure per square inch; this is true when the wheel is perfectly round and the shoe truly concentric with it. There is, however, a growing tendency to use long

brake shoes, because they not only tend to keep the wheel round, but since the pressure per square inch is less, they last longer.

57. Condition of Rail.—An important factor to be considered on trolley roads is the condition of the rail. The T rail on steam roads is mostly laid in the open country and offers very little inducement to the accumulation of snow and slush upon its top. Where a T rail is used in trolley-road construction, it has the same advantages. Trolley roads have paving conditions to contend with and must use a girder rail, whose flat top and open groove are very inviting to foreign substances.

When the rail is slippery, it is an easy matter to apply too much brake pressure, thereby causing the wheels to slide and make flat spots on them. To offset the disadvantage of a slippery rail, it is the custom to use sand. The use of sand greatly improves the rolling friction between wheels and rail, but most managements make the mistake of sanding only one rail instead of two. With sand on one rail, the rolling friction averages 30 per cent. of the weight on the wheel.

58. When a car rests upon a rail, there is a certain amount of friction between the wheels and rails, and this friction increases as the weight on the wheels increases. It would take a certain number of pounds pull on the rim of a wheel to turn it against the friction of the rail without moving the car. Also, when the car is in motion, if, in the effort to stop the car by means of the brakes, the latter are set up so tight as to lock the wheels and cause them to slide, the friction between the wheels and rails tries to make the wheels roll again. It is this friction that in the previous article was said to be 30 per cent. of the total weight of the car. The total pressure to be applied to the brake shoes depends on the leverage of the brake rigging, on its condition, and on the pull on the brake handle. The fraction of this pressure that actually retards the motion of the car depends on the friction between the shoes and wheels.

59. Fig. 59 shows a very common form of single-truck brake rigging, most of the parts of which are designated in the figure. Brake beams *B*, *B* are supported on the ends and slide in cast-iron pieces fixed to the side frames of the truck; they are called *brake-beam castings*. Fig. 60 shows the general idea. *A* is the slide casting, *B* the beam, and *F* the truck member that supports the casting. Equalizer rods *r*, *r* (see Fig. 59) connect to equalizer bars *E*, *E* and are erroneously said to equalize the pressure on all brake shoes. Under the most favorable circumstances, they partially equalize the pressures against the two wheels on the same axle. Each equalizer rod ends in a jaw *J*, to which the equalizer bars are rigidly connected, but in which the brake beams move freely. Fig. 61 shows the construction. *R* is the rod; *J*, the brake jaw; *B*, the beam; and *E*, the equalizer bar. In Fig. 59, links *H*, *H* are connected to the brake levers *L*, *L* and equalizer bars by means of pins. Links *I*, *I* connect the brake lever and brake beams. *F* is a pin around which *L* and *E* can move and F_1 is a pin in common to *L* and *B*. In the diagram, the brakes are shown to be off and the shoes have been pulled away from the wheels by the release springs. One end of each

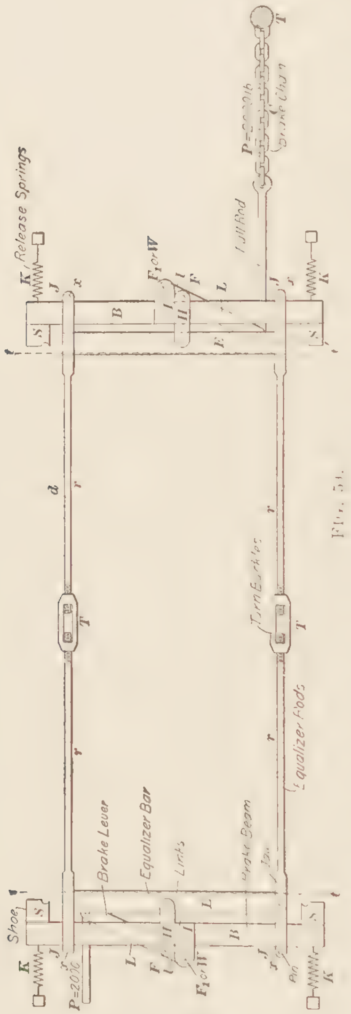


Fig. 59.

spring is fixed to a lug on a car truck and the other end to the brake beam or shoe head. Brake slides wear badly and give trouble in winter time by getting stopped up with frozen mud; the main objection is that the harder the brakes are set, the harder the brake beams press against the brake slide castings, with the final result that the harder the brakes are set, the harder it is to set them. The operation of the brake will be apparent from an examination of Fig. 59. The force exerted on the pull rod P draws the brake beams B, B together, and thus presses the shoes S, S against the wheels.

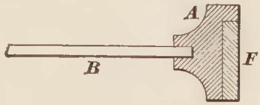


FIG. 60.

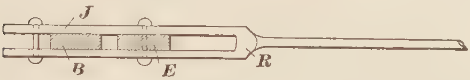


FIG. 61.

POINTS ON CARE OF RIGGING.

60. The main points to be observed in caring for brakes on single trucks are the following: See that all brake-staff bearings are kept lubricated. They should be oiled frequently, using but little oil at a time, to avoid soiling the passengers' clothes. The brake-staff ratchet wheel should not be allowed to run with teeth missing nor should the dog be allowed to have a blunt point; both should be renewed as soon as defective. Particular care should be taken to see that the action of the ratchet brake handle is perfect. If the handle ever fails to catch while being applied and the clicking noise emitted on release seems to be weak, it means that the dogs inside the handle hub have become blunt or that the springs pressing them into the ratchet have become weak; such a condition should be reported at once, as it is liable to cause a serious accident.

61. Should the brake handle appear to be much harder to turn at one point of its revolution than at all others, it

probably means that the brake staff is bent. To avoid this, the brake staff should be well supported on its lower end, where the greatest strain comes. The brake chain should be fastened to the staff, so that it will wind upon the staff and not on itself; otherwise, the leverage will decrease as the brakes are applied. In case there are any tripod brackets to support the lower end of the brake staff, care should be taken that the legs of the brackets are so disposed as not to interfere with the winding up and paying out of the brake chain.

62. Inspection of Parts.—All brake-chain fastenings should be inspected every day. Every small amount of wear weakens a chain, and it is only a question of time when it will get weak enough to break. Defects are often caused by some rod or lever rubbing on a part of the car or some other device. When a brake rod is interfered with, the friction not only puts extra work on the motorman, but it may also put so much work on the release springs that they become useless. The constant rubbing will weaken the rod, so that in course of time it will break. All rods and levers may clear everything when the car is light and interfere with each other or some part of the motor rigging when the car is loaded. A rod may clear a wheel of one type and interfere with another whose dish is greater. An excessive end play in the axle collars will let the motor over against the brake rods. An excessive load on a car whose springs have become weak may let the rods down on top of a gear case or motor. In placing or inspecting a set of rigging, all these points must be kept in mind, making due allowance for the effects in the increased weight on the car body, weakening of the truck springs, and wear on the moving parts of the brake rigging. All turnbuckles, brake slides, fulcrums, and, on double-truck cars, the strap hangers, in which parts the brake rigging slides, should be kept lubricated. Release springs should be renewed when they become too weak to pull the shoes to off-position.

DOUBLE-TRUCK HAND-BRAKES.

63. Single-truck and double-truck brake riggings differ in two and sometimes three respects. A double truck consists of two single trucks, each of which has a complete set of brakes of its own. Both of these trucks revolve around independent centers, so that means must be provided to preserve the efficiency of the brakes whatsoever may be the angle that either truck makes with the center line of the car body. The third feature of difference depends on whether all the wheels on a truck are the same size or not. If they are, constituting what is known as an ordinary double truck, each of the eight wheels on the car has the same weight resting upon it, so that each shoe must have the same pressure applied to it. If, however, the truck has two large wheels and two small ones, constituting the so-called maximum-traction truck, the truck is so disposed that the large wheels support from 60 to 70 per cent. of the weight of the car.

64. Fig. 62 shows a truck rigging, the action of which explains itself. If the shoes are properly adjusted, a pull of 2,000 pounds at P will give each shoe a pressure of 5,000 pounds, if the leverage of PFW is 10 to 1, bearing in mind that the figure shows the rigging on only one side of the truck.

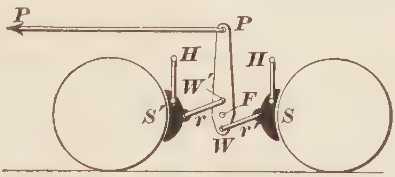


FIG. 62.

65. Fig. 63 shows two such truck riggings adapted to a double truck; the long lever PP is secured to the car body through fulcrum F, which is, therefore, stationary. Fig. 64 shows the device used to compensate for the rotation of the truck on curves. C, C are two pieces of steel bent to an arc to suit the rotation of the truck. These bent pieces of steel are variously called "circle bars," "arch bars," and "existing arches," and the pull rods from the

respective trucks connect to their ends. Tension rods X, Y carry on their ends a grooved wheel through which the

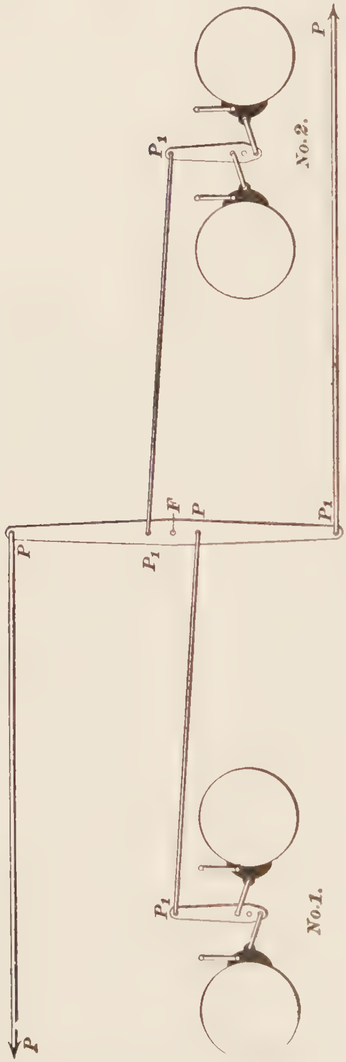


FIG. 63.

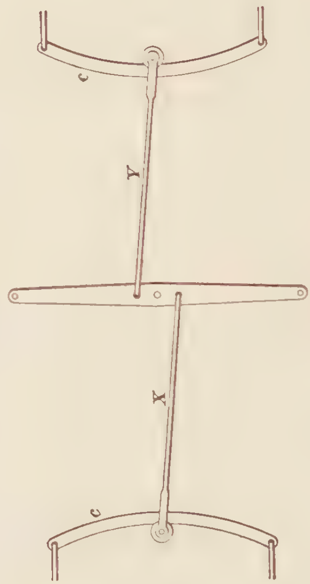


FIG. 64.

circle bars roll as the truck rotates, thereby preserving the position of the brake rigging.

66. Fig. 65 is a diagrammatic sketch of one-half the rigging used on a maximum-traction truck, where most of the weight is on the large wheels, so that most of the pressure must be applied to them. *PWF* is the truck brake lever whose fulcrum is fixed to the truck at *F*. A rod *R* runs from *W* to the brake beam on the larger wheel; at *x* the

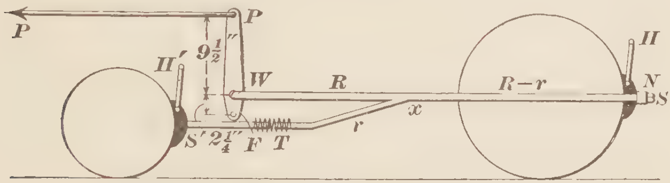


Fig. 65.

rod branches, the branch rod *r* returning to the brake beam on the smaller wheel. The branch rod is not continuous, but acts through a spring *T*, whose resistance can be regulated by means of a nut not shown in the diagram. The resisting force of spring *T* and its amount of compression are an exact measure of the pressure exerted on shoe *S′*.

AIR BRAKES.

CLASSIFICATION.

67. Air brakes, as used on electric cars, may be divided into two classes, known as *straight air* and *automatic air*. In both classes, the brakes are set by allowing compressed air, stored in a reservoir, to expand into a *brake cylinder*, thus moving the piston and operating the brake levers. In a straight air equipment, the devices are such and are so arranged that the compressed air passes directly from the reservoir into the brake cylinder without passing through any automatic device. In an automatic air equipment, however, this is not so. Figs. 66 and 67 are diagrams illustrating the difference. In Fig. 66, when valve K_1 is

open, pump P stores air in reservoir R, until gauge G shows the desired maximum pressure; K_1 is then closed. To apply the brake, valve K is opened; the air in R then expands into B, pushing on piston P_1 and shoving S against W. To release the brake, valve K is closed and K_2 opened, allowing the air in B to escape to the atmosphere, so that release

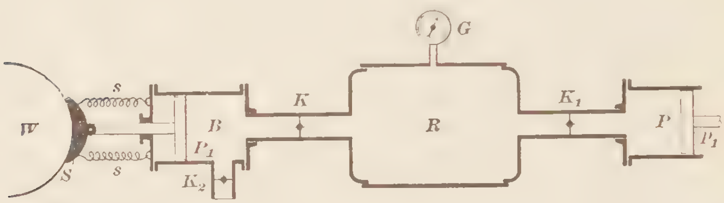


FIG. 66.

springs s, s can pull the shoe from the wheel. Valves K and K_2 should never be opened at the same time, as this allows air to pass from R direct to the atmosphere, causing a great waste of air. In actual practice, valves K, K_1, and K_2 are operated by a single handle in such a way that wasteful connections cannot well be made.

68. In. Fig. 67, the main reservoir M is kept stored by a pump, both being on the engine or motor car. On each coach or trailer is an auxiliary reservoir R, a device called a triple valve, and a brake cylinder B. M, R, and B connect to the triple valve, as shown. The triple valve is automatic in action and has three duties to perform. It must make an opening between M and R, so that M can store air in R; it must connect R and B to apply the brake; and it must connect B to the atmosphere to release the brake. Piston p of the triple valve can move back and forth. Chamber A always carries main-reservoir pressure. The chamber on the left of piston p always carries auxiliary pressure. If the pressure in M exceeds that in R, p is forced to the left, as shown in the figure. In this position, air from M leaks through groove g and stores R until M and R are at the same pressure. To apply the brake, the pressure in the pipe connecting M

to the triple valve is reduced by letting out some of the air in it. This makes the pressure in chamber A less than that in

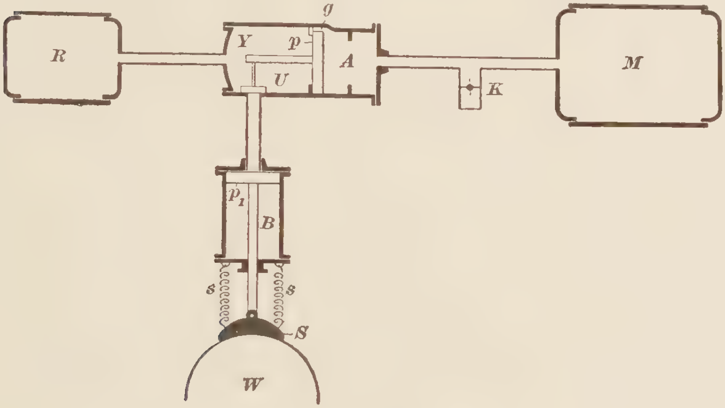


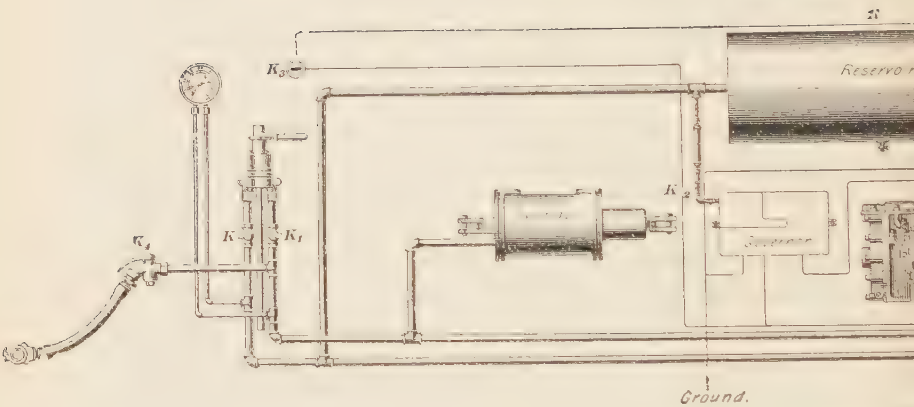
FIG. 67.

the auxiliary reservoir, thereby moving piston p to the right, uncovering the pipe leading to B, and opening up communication between R and B; this forces down piston p_1 and sets the brake. To release the brake, the motorman, by means of his operating valve, reestablishes communication between M and its connecting pipe, thereby raising the pressure in chamber A above that of the auxiliary reservoir R, so that p moves to the left and again closes communication between R and B. At the same time, by means of a valve, also operated by the stem of piston p, but not shown in the figure, communication is established between cylinder B and the atmosphere, thus letting the air out of the cylinder and allowing the release springs to release the brakes.

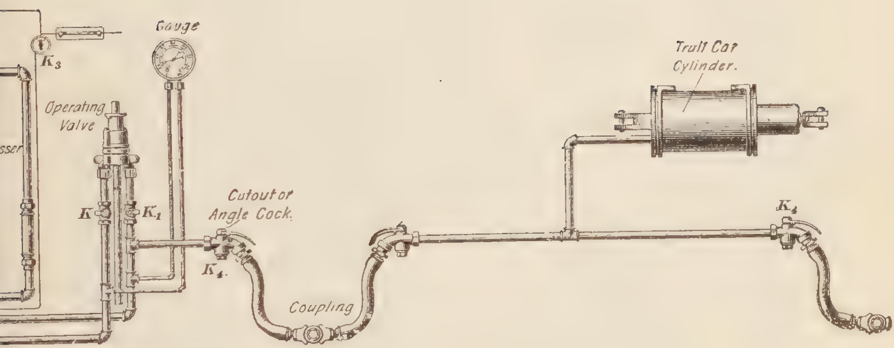
Automatic air brakes are used on long trains, because they allow the brakes to be set on all the cars at the same time. For ordinary trolley cars, where only single cars or a single car and trailer are operated, the straight air equipment is simpler and safer than the automatic air. The use of automatic air on electric cars is, therefore, confined principally to elevated and underground roads, where heavy trains of considerable length are operated.

69. Straight Air Equipment. Fig. 68 shows the general arrangement of a Christensen straight air equipment as used with a trolley car and trailer. The outfit consists of an air compressor that is driven by a small geared motor; this compressor is usually well cased in and hung from the under side of the car. The motor that drives the compressor is controlled by an automatic governor that starts the motor when the pressure gets below a certain amount and stops it when the air has been compressed to the required pressure, usually about 60 pounds per square inch. The compressor stores the air in reservoir R, and from this reservoir it is allowed to flow into the brake cylinder by means of the operating valves at either end of the car. K, K are cut-out cocks in the reservoir pipe and K_1, K_1 are cut-out cocks in the brake-cylinder pipe. The cocks K_4, K_4 are for connecting on other cars, as indicated. The motor circuit of the compressor is controlled by two snap switches K_3, one at either end of the car, so that the motor may be cut out from either end or so that the motor may be controlled by hand in case anything goes wrong with the automatic governor. At each end of the car there is a gauge, provided usually with two hands; a red hand to indicate the reservoir pressure and a black hand to indicate the pressure in the brake cylinder.

70. The Brake Valve.—The brake valve, generally called the **engineer's valve,** is a device by means of which the motorman applies and releases the brake. It is located on the car platform between the hand-brake and the controller. The brake valve has three duties to perform. It is provided with a handle that controls the performance of these duties. In one position of the handle, the reservoir and the brake cylinder are connected, thereby setting the brakes. In a second position, the brake cylinder and the atmosphere are connected, thereby releasing the brakes. In a third position, all air passages are blanked so that there can be no movement of air in any direction.



FIG



Gauge
K_3
Operating Valve
sser
K
K_1
Cutout or Angle Cock.
K_4.
Coupling
Trail Car Cylinder.
K_4

71. Fig. 69 shows the nature of the operations that the brake valve performs. B_1, E_1, and R_1 are three pipes leading from the brake cylinder, atmosphere, and reservoir, respectively, to the brake valve; on top of the valve body is a cap (b) that turns around b_1 as a center and has in it a slot c c. In the position shown in the diagram, the handle points front and the ports to which E_1 and R_1 lead are covered by the under side of the valve cap and do not, therefore, communicate with each other or with the port leading to pipe B_1. If, however, the valve handle is moved to the right, the slot in the cap connects ports B_1 and R_1 and air passes from the reservoir to the brake cylinder and shoves piston p to the dotted position p_1, thereby setting the brakes. If the cap handle is moved back to the vertical position, all the ports are again blocked and the air in the brake cylinder must remain there and keep the brakes set. By moving the valve handle to the left, ports B_1 and E_1 are connected, thereby allowing the air in the brake cylinder to escape to the atmosphere and permitting the release springs to pull the piston back to its normal position. The engineer's valves made by different manufacturers differ considerably in detail, but the operations that they perform are essentially those just outlined.

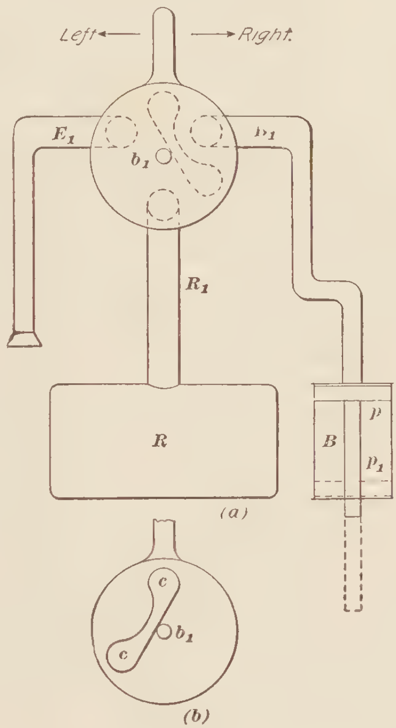


FIG. 69.

72. Positions.—Fig. 70 is a top view of the Christensen valve as it appears on a car. The dotted circles indicate the exhaust, reservoir, and brake-cylinder connections, as marked. There are five positions—namely, *lap*, *service stop*, *emergency stop*, *slow release* and *running*, *quick release*. The brake handle can be removed only on the *lap* position. In the *lap* position, the handle points towards the motorman; all ports are blanked so that none of the three pipes can communicate with each other. If there is any air in the brake cylinder, it is held there.

To make a **service stop**, the operating handle is moved to the right into the **service** position. In the service position, a small opening is created between the reservoir and

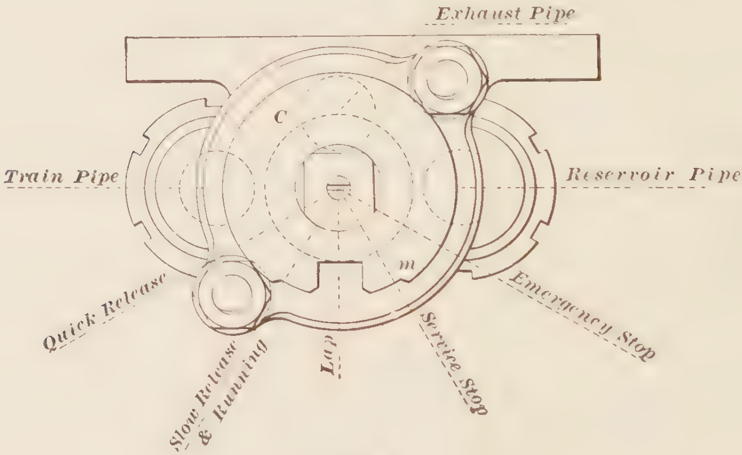


Fig. 70.

brake cylinder, so that compressed air passes from the reservoir into the cylinder; as this opening is small, the flow of air is gradual and the degree to which the brakes are set depends on the length of time that the valve is allowed to rest in the service position. If in making a service application, the motorman finds that the car is going to stop too soon, he releases the brakes a little by letting a little air out of the brake cylinder; this is done by throwing the operating handle to the *slow-release position.*

In the **slow-release** position a small opening is created between the brake cylinder and exhaust pipe, thereby letting some of the compressed air in the brake cylinder escape into the atmosphere; this lowers the pressure in the brake cylinder and tends to release the brakes. If the handle is left on the slow-release position too long, the brakes will release entirely.

When the valve handle is moved to the **full-release** position, the air in the brake cylinder escapes to the atmosphere in a single puff; this gives the release springs a chance to pull the brake piston, levers, and shoes to the release position.

If the operating handle is moved to the right as far as it will go, a full and unobstructed passage is opened between the reservoir and brake cylinder, thereby allowing the full reservoir pressure to act upon the brake piston and immediately setting the brakes with full force. This position is known as the **emergency** position.

THE GOVERNOR.

73. Wherever a motor-driven compressor is used, means must be provided for starting the compressor when the pressure in the reservoir becomes too low and for stopping it when the pressure reaches the value at which it is intended to operate the brake.

74. The Christensen Governor.—A top view of the automatic governor or "automatic" used on the Christensen air-brake equipment is shown in Fig. 71. *L* and *R* are electromagnets; *A A* is an armature or plunger that can slide back and forth between the magnets and carries an arm to which the finger *K* is fastened by means of the insulating block *I*. When an electric current is made to pass through the magnet *L*, the plunger or armature *A A* is pulled to the extreme left-hand position. Finger *K* makes contact with finger *K'*. When a current passes through the magnet *R*, the armature is pulled to the right and the motor

circuit of which K and K' are a part is opened. D is a coil through which all current that goes to the motor must pass; this coil acts as a magnetic blow-out to extinguish the arc that forms between K and K' before it can burn or blister them and thereby impair their electrical contact.

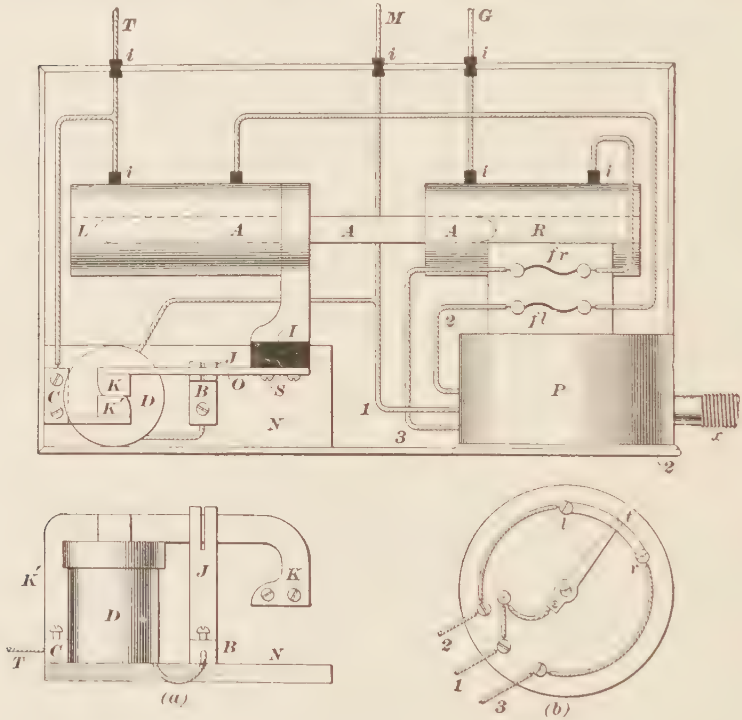


FIG. 71.

When fingers K, K' are pulled apart, the open circuit lies between terminals C and B. In other words, when the fingers K and K' touch each other, the current coming in on the trolley wire T takes the path T–C–K'–K–J–B–D through the blow-out coil and to the wire M that leads to the motor circuit.

75. P is the *regulator* that determines which of the two magnets R and L shall get current and these determine whether or not the compressor motor shall run, because

when L gets a current, K and K' touch; but if R gets a current, they do not. P is a contact maker or circuit opener and closer, whose action is exactly the same as that of a pressure gauge. The hand of the gauge, instead of being used to indicate pressure on a scale, is made to carry on its end a little carbon knob t, Fig. 71 (b), that plays between contact buttons. These contact buttons are lettered l and r, because when t touches button l, magnet L gets a current; and when t touches r, magnet R gets current. Pipe connection x goes to the reservoir or to one of its pipes, as shown in Fig. 68; f_r, Fig. 71, is a fuse in circuit with magnet R and f_l is a fuse in circuit with magnet L. One end of fuse f_r leads to connection *3* in the rear of the regulator and from there to contact button r. The other end of the fuse goes to magnet R. One end of fuse f_l goes to post *2* on the rear of the regulator and thence to contact button l; the other end of the fuse goes to magnet L. The middle contact post *1* on the rear of the regulator connects to the hand that carries the carbon knob t, and since the hand moves, the connection is made by means of a very flexible wire. Post *1* also connects on the outside to the wire that runs from the blow-out coil D to the motor circuit. All shaded parts marked I or i are hard-rubber insulating parts. Wires T, M, and G are the main governor wires leading to the car trolley wire, the pump motor, and the car ground wire, respectively.

Fig. 72 is a diagram of the connections of the governor. The regulator hand t, Figs. 71 (b) and 72, is so adjusted that when there is no pressure in the reservoir, and therefore no force within the air lobe that operates it, a spring forces the carbon knob against contact post l. Suppose that there is no air in the reservoir and that it is necessary to start the pump to get up pressure; the carbon knob t touches the contact l. Current comes in at T to point X, Fig. 72; if magnet L was the last one to operate and the armature A A is, therefore, in its extreme left-hand position, as indicated in Fig. 71 (a), fingers K and K' make contact, thereby connecting points B and C, Fig. 72, so that the current splits at X;

part of it takes the path *X–C–B–D–Y–M–M'–W–Ground* and starts up the pump motor, and part of it takes the path *X–L–*f_l*–l–t–Y–M–M'–W–Ground* through the left-hand magnet coil *L*, exciting it. In this particular case, where the armature *A A* and the finger *K* are already at the extreme left-hand end of their travel, magnet *L* does not do anything. Suppose that at the time the pump switches were closed, armature *A A* happened to be so far to the right that fingers *K* and *K'* failed to touch each other. In this case, when the current gets to *X*, it cannot go through the pump

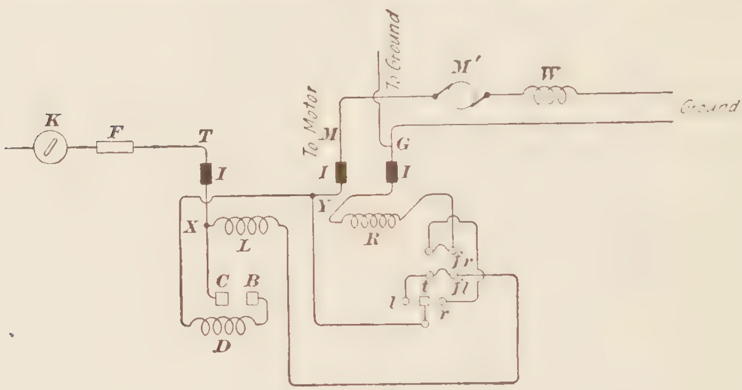


FIG. 72.

motor and start the pump, because the circuit is open between *B* and *C*. But it does take the path through the left-hand magnet, which then pulls the armature *A A* to the left, causes *K* and *K'* to touch, and starts the pump. It is true, as can be seen in Fig. 72, that the current that passes through magnet *L* to pull *A A* over to the left also must pass through the pump motor to reach the ground; but on account of the resistance of magnet *L*, this current is too small to start the motor.

76. As the pressure in the regulator increases, due to an increase in the reservoir pressure, contact *t* is pulled away from contact post *l* and interrupts the flow of current through magnet *L*, Fig. 72. Armature *A A* still remains at the extreme left-hand end of its travel; contact

fingers K, K' still touch each other; and the pump motor still works, for there is as yet no influence brought to bear to pull the armature to the right.

77. As the pressure in the reservoir increases, the carbon knob t moves slowly away from contact l towards contact r. As soon as it touches contact r, current from the trolley wire takes the path T–X–C–B (remember that fingers K and K' on contact blocks C and B still touch each other) D–Y–t–r–f_r–R–G. Magnet R pulls armature $A\ A$, Fig. 71, quickly to the right, pulls fingers K and K' apart, and stops the pump motor. At the same time, since coil R gets its current from the motor-circuit trolley wire at point Y, which is on the negative side of the contact breaker $K\,K'$, as soon as the circuit opens between K and K', magnet R can no longer get any current and can exert no pull on $A\ A$, which, however, lies there until a fall in the pressure causes the knob t to drop back on contact l, once more pulling $A\ A$ to the left.

78. The Standard Air-Brake Governor.—The governor used by the Standard Air-Brake Company is somewhat different in principle from the Christensen governor just described. Fig. 73 is a general view of the device and Fig. 74 shows the electrical connections. In Fig. 73, S is a heavy spring that acts against the reservoir pressure in cylinder C to determine the position of lever L, which, by means of a connecting-rod, moves switch blade *14*, Fig. 74, in and out of contact jaws *13* and *15*. d is an iron-enclosed electromagnet that has

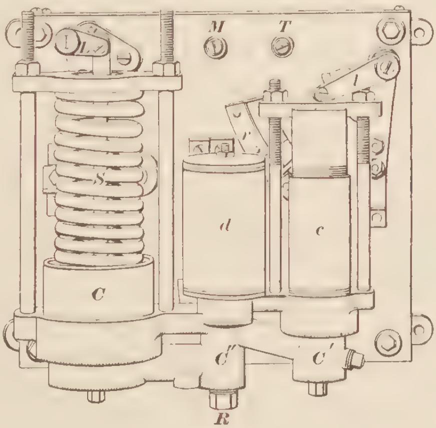


FIG. 73.

within it a plunger that is free to move down or up, according as d is excited or not. In chamber C'', Fig. 73, is a spring that pushes up on a cone-seated pin valve. Chamber C'' admits air to cylinder C' when the pin valve is in the proper position and cylinder c carries a piston whose stem operates lever l to move a contact arm over plates r, r, Fig. 74, thereby cutting resistance in or out of the motor circuit, as occasion may demand. The reservoir pipe is connected at fitting R, Fig. 73. The piston in cylinder C is pressed down by spring S and up by the reservoir pressure below it. Spring S is so designed that it can keep the piston down and switch *13–14–15*, Fig. 74, closed when the reservoir pressure acting against it is less than 50 pounds to the square inch. As soon as the reservoir pressure gets above 50 pounds, it begins to compress spring S and moves lever L counter-clockwise. Immediately a rod, also connecting lever L to the switch mechanism, starts to pull on this mechanism, which is so designed that it does not actually pull the switch out until the pressure reaches 60 pounds per square inch. The switch is pulled out by a spring that snaps it out to avoid any arcing. When the reservoir pressure is below 50 pounds, the piston in C, Fig. 73, is at the lower end of its travel and the switch is in, so that the pump motor runs and raises the pressure. As soon as the pressure gets above 50 pounds, it compresses the spring S, raises the lever, opens the switch, and stops the motor at 60 pounds.

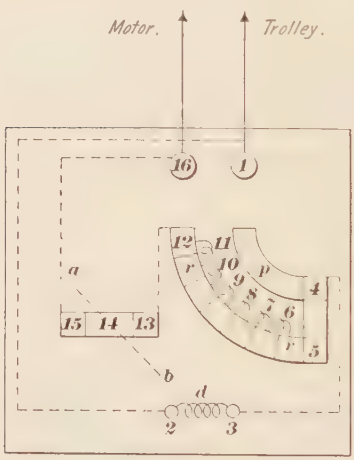


FIG. 74.

79. This arrangement alone would constitute a governor, for the pump is started when the pressure reaches

normal value. But the Standard people do not approve of starting even a series motor at frequent intervals, by placing it dead across the line without any resistance in ahead of it.

80. With this governor, whenever the motor is started, a resistance is placed in series with it. As stated before, there is a spring in chamber C'', Fig. 73, that ordinarily presses up on a double-seated pin valve and closes all communication between chamber C' and the reservoir. A spring keeps the piston in cylinder c at the lower end of its travel when there is no air pressure admitted to chamber C' to force up the piston. In this position, lever l is down, as shown in Fig. 73, and contact arm *4–5*, Fig. 74, is in the position shown; all resistance is in.

81. The connections are shown in Fig. 74; post *1* takes the wire from the pump-motor snap switch and fuse box and is also connected to post *2*, to which one terminal of coil d also connects. Post *16* connects to one jaw of main switch *13-14-15*, and plate *12* of the series of resistance plates connects to the other jaw of the switch. When the switch is closed, as shown in the figure, the spring blade *14* connects jaws *13* and *15*; but when the switch is open, the blade takes the position indicated by the dotted line $a\ b$ and no current can get from jaw *13* to jaw *15*. Post *3* connects to plate p. If switch *14* is closed, current comes in on post *1*, takes the path *1–2–3–4–5–6–7–8–9–10–11–12–13–14–15–16*, on through the pump motor to the ground. All resistance is cut in, as contact arm *4–5* is on the first plate, which position is caused by the piston in cylinder c being at the lower end of its travel, thereby pulling down the lever l, Fig. 73.

82. Operation.—Now, when the air in the reservoir is up to standard, spring S is somewhat compressed by the standard pressure under the piston on which it sets, switch *14* is open, and the pump is stopped; also, there is no air under the piston in cylinder c, because the spring in chamber C'' presses up on the pin valve and closes it. As soon as an application of the brakes or leakage causes the pressure in the reservoir to fall below 45 pounds per square

inch, spring *S* pushes down the piston and stem and closes switch *14*, Fig. 74, allowing the pump motor to start.

Since resistance arm *4–5* is in the position shown in Fig. 74, all resistance is in and the starting current is small. The moment switch *14* closes, the starting current passes through coil *d* also and pulls down its core. The core presses down on top of the pin valve harder than the spring in chamber C'', Fig. 73, presses up; the result is that the valve is pushed off its seat, air is let into chamber C', which raises the piston and stem connections to lever *l*, moves contact arm *4–5* clockwise, until it gets to plate *12*, where all resistance is cut out and the pump motor runs at full speed. As soon as the reservoir pressure reaches standard value and switch *14*, Fig. 74, opens, magnet *d* becomes dead, the spring in chamber C'', Fig. 73, once more closes the inlet end of the pin valve, the compressed air in the cylinder *c* escapes to the atmosphere, and the piston stem, lever *l*, and resistance contact arm *4–5* resume their normal positions.

THE BRAKE CYLINDER.

83. Fig. 75 is a sectional view of a brake cylinder. *4* is the piston; *13*, the hollow piston stem; *8*, the release spring; *2*, the front head; *3*, the back head; *1*, the cylinder body; *12*, the head bolts; *11*, the bolts for securing the packing to the piston; and *6*, *7*, the forks through which pass bolts *15* and *16* and around which turn the brake levers.

84. Operation.—Fork *6* is stationary; fork *7* moves back and forth with the push rod *P*, which moves with the brake levers. When air is let in at the right-hand end of the cylinder, piston *4* is forced to the left, carrying with it push rod *P*, which moves the lever connected to pin *16* and sets the brakes. In moving to the left, piston *4* compresses spring *8*, so that when the brake valve is put on release position, letting all the air in the cylinder pass to atmosphere, spring *8* returns piston *4* and piston stem *13* to the normal position. Since fork *7* and push rod *P* are independent of

piston stem *13*, the push rod must be returned to normal position by the release springs on the brake rigging. The object of having *P* and *13* independent of each other is so that when the hand-brake is used and push rod *P* must be pulled out, it will not be necessary to pull out *4* and *13* against the action of spring *8*. The travel of the brake piston should be kept within the limit prescribed by the brake company. After this limit is passed, the side pressure of the push rod *P* on the hollow stem *13* may be great enough to bend the rod or split the stem.

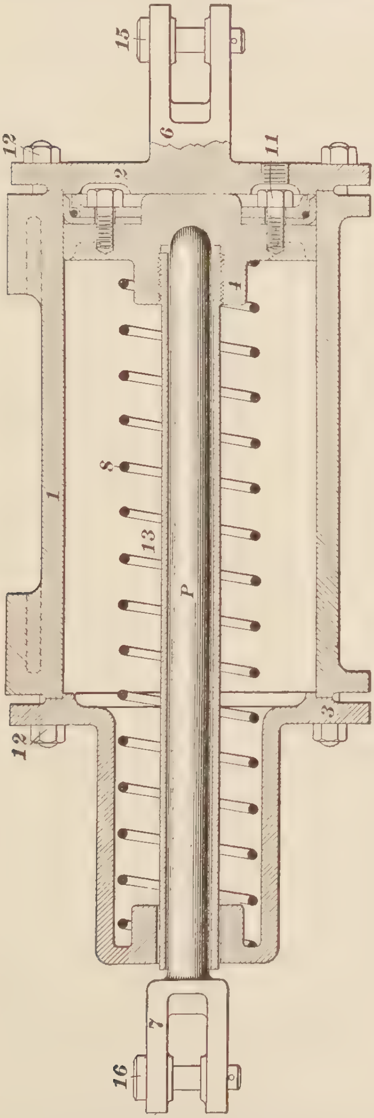
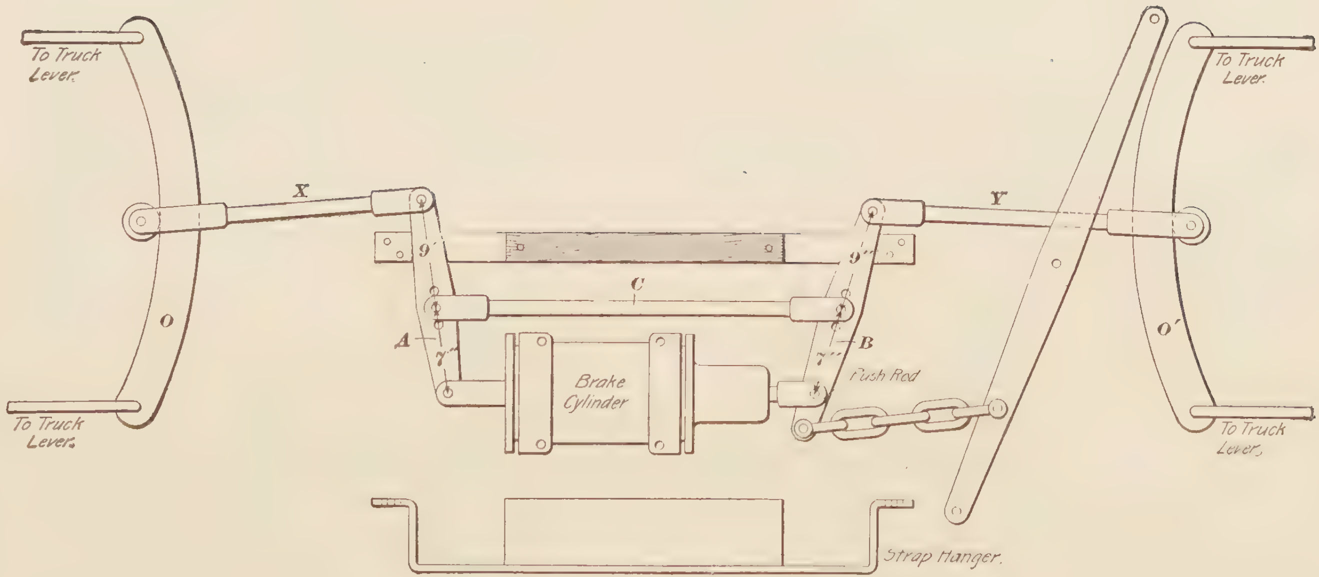


FIG. 75.

LEVER SYSTEM.

85. Fig. 76 shows a system of air-brake levers recommended by the Christensen Company. The diameter of the brake piston is in this case 6 inches and its area, in round numbers, is 28 square inches. Supposing that the reservoir has a pressure of 60 pounds per square inch and that full pressure is let into the cylinder, the total pressure on the piston that shoves on



To Truck Lever.
To Truck Lever.
To Truck Lever.
To Truck Lever,
X
Y
O
O′
9′
7′′
9′′
7′′
A
B
C
Brake Cylinder
Push Rod
Strap Hanger.

FIG. 76.

the push rod and sets the brake is $28 \times 60 = 1,680$ pounds. A and B are the two levers that apply the brake; one end of A is fixed to the back head of the cylinder, the other end attaches to the tension rod X. One end of B connects with the push rod and the other end with the tension rod Y. Levers A and B are also connected through the tension rod C. Air admitted to the cylinder causes the push rod to move to the right, carrying with it the lower end of lever B. Using rod C as a fulcrum, lever B pulls on rod Y. Using rod Y as a fulcrum, lever B pulls on rod C.

When the hand-brake is used, the push rod is pulled in and out of the hollow piston that holds it. It will be noticed that the air brake and hand-brake operate in the same direction, so that if the air brake were applied with the hand-brake already partially set, there could be no danger to the motorman or the brake rigging.

THE ELECTRIC BRAKE.

86. Electric brakes are operated by making the motors act as generators to supply the necessary current. They may thus be operated no matter whether the trolley wheel is on the wire or not and do not take any additional current from the power station. In order that the brakes may take hold, the car must be in motion; hence, electric brakes cannot hold a car on a grade, although they may bring it nearly to a standstill. To hold the car, the hand-brakes must be applied. The electric brake that has so far been most largely used is that manufactured by the General Electric Company; we will, therefore, describe it briefly.

87. Fig. 77 shows the brake used on a motor car. It consists of a cast-iron ring split horizontally and held together, as shown, by bolts. As indicated by the dotted lines, there are magnetizing coils C, C in each half of the ring. Each coil consists of 32 turns of No. 8 wire. The

sectional view shows how the coils are embedded in the iron and held in place by pouring in lead *P*, *P*, the insulation of the coil being protected from the hot lead by a thin layer of asbestos, not shown in the figure. The wearing plate *W*

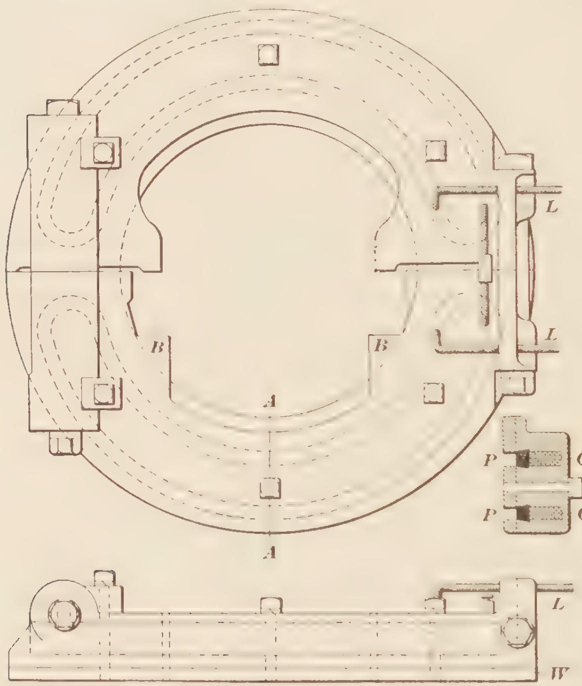


FIG. 77.

is in two pieces, one on each half of the brake ring and held on by capscrews. The two magnetizing coils are in series, connection with the car wire being made by means of leads *L*.

88. Fig. 78 shows the manner of *support*. The motor-bearing cap *C* has two projecting horns *A*, one behind and the other in front of the car axle. Lugs *B*, Fig. 77, of the brake ring rest on these horns, and thus the brake is held close to the disk *S* that turns with the axle. Setscrew *M* is used to take up the wear in the disk and ring. The ring

has $\frac{1}{32}$ inch end play, but cannot rotate at all; hence, when it is magnetized, it draws itself over, clutches disk *S*, and tends to prevent its turning, thereby acting as a brake. Both the disk and ring are provided with wearing plates *W*.

So far as the motorman is concerned, the addition of the brake attachment does not add complications to either his cares or operations. On the main controller drum is a neutral position; on one side of this position are the power

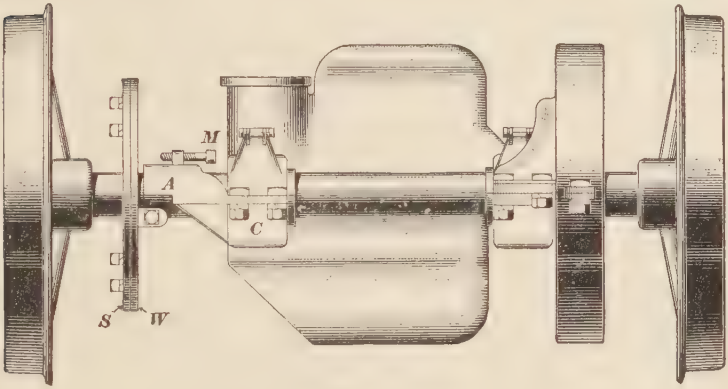


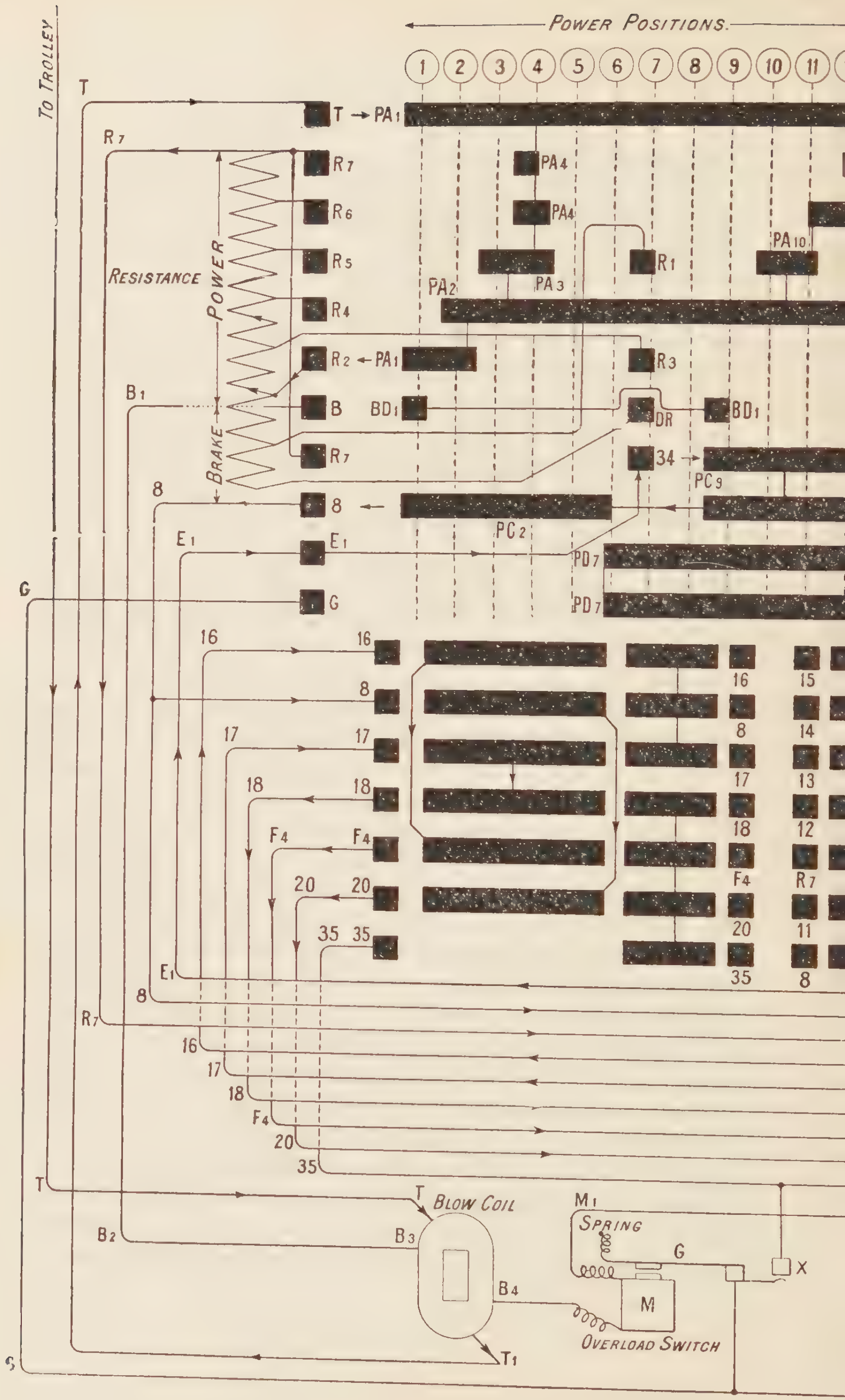
FIG. 78.

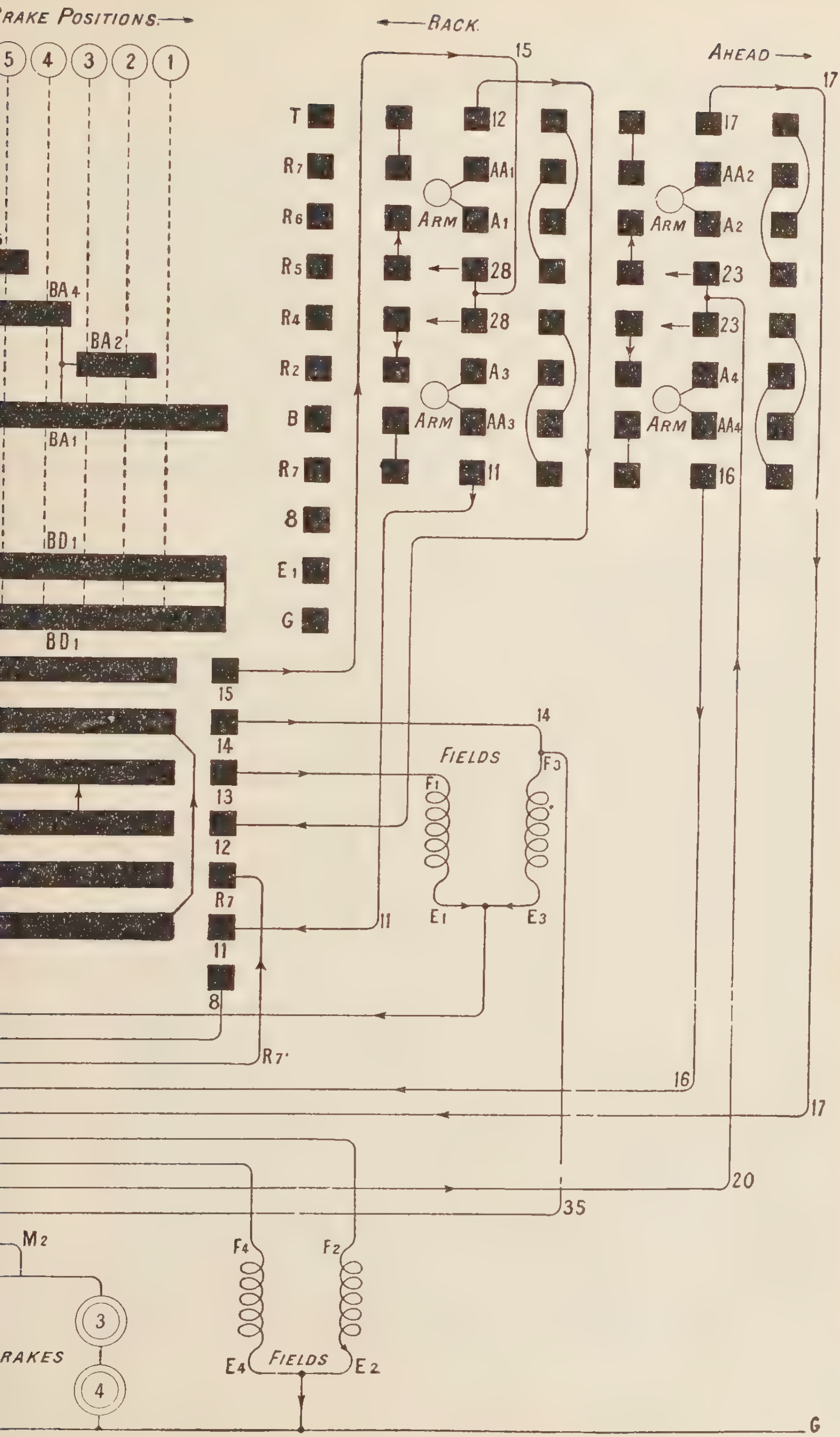
contact tips and on the other the brake contact tips. To start the car, the controller handle is operated as usual; to throw the current "off," preparatory to making a stop, the handle is thrown to the off-position, as usual; to apply the electric brake, the handle is simply kept moving past the off-position. To release the brake, the handle is returned to the off-position.

THE CONTROLLER.

89. The Main Drum.—The main drum is shown in the left-hand upper corner of Fig. 79. This drawing shows the connections for electric brakes used with a four-motor equipment with the B6 controller. There are 11 rows of contact tips. All tips that are marked with the same letter

are metallically connected and the subjoined figure indicates the position on which the tip comes into action For example, PA_1 indicates that the tip is a power tip, that it is a part of the *A* drum casting, and that it comes into action on the first power position. PA_{10} is a power tip on the *A* casting and comes into action on the tenth power position. BA_4 is a brake tip of the *A* casting and comes into action on the fourth brake position. All the tips marked *A* are connected; if the *A* is preceded by a *P*, it is used in applying the power to start the car; if it is preceded by a *B*, it is used on a brake position to stop the car. Thus it will be seen that some of the castings have tips, such as PA_1 and BA_2, etc., in common to applications of both the power and the brake, but are not in use at the same time. On the left of the main drum are shown the 11 main-drum fingers, *T*, R_7, R_6, R_5, R_4, R_2, *B*, R_7, *8*, E_1, and *G*. On the right of the main drum, these fingers are reproduced, not because there are actually two rows of fingers, but simply to make it easier to trace current paths; therefore, no wires are run to these fingers. When the car is being started, the student will imagine the main-drum contacts to move towards the left-hand row of fingers; when it is stopped, the drum moves towards the right-hand row. Thus on the first power notch, fingers *T*, R_2, *B*, and *8* make contact on the left-hand end of the drum; on the first brake notch, fingers *B*, E_1, and *G* touch the right-hand end of the drum. The row of enclosed numbers, beginning at *1* on the left and running up to *12*, shows the positions used in applying the power; the row beginning at *1* on the right shows the positions used in applying the brake. There is, therefore, a portion of the main drum, between power position *12* and brake position *6*, not touched by the fingers at all. This untraversed space is dictated by the width of the lug on the controller top; when the controller handle gets to the full multiple position, the twelfth position, one side of the lug stops it; when it gets to the last brake notch, the sixth position, the other side of the lug stops it.


To Trolley
Power Positions
1
2
3
4
5
6
7
8
9
10
11
T
T → PA1
R7
R6
R5
R4
R2 ← PA1
B
8
E1
G
Resistance
Power
Brake
B1
PA4
PA4
PA3
PA2
R1
PA10
R3
BD1
DR
BD1
34
PC9
PC2
PD7
PD7
16
17
18
F4
20
35
15
14
13
12
11
Blow Coil
B2
B3
B4
T1
M1
Spring
M
X
Overload Switch


RAKE POSITIONS
5 4 3 2 1
BACK
AHEAD
15
17
T
R7
R6
R5
R4
R2
B
R7
8
E1
G
12
AA1
ARM
A1
28
28
A3
ARM
AA3
11
17
AA2
ARM
A2
23
23
A4
ARM
AA4
16
BA4
BA2
BA1
BD1
BD1
15
14
13
12
R7
11
8
14
FIELDS
F3
F1
E1
E3
11
R7'
16
17
20
35
M2
F4
F2
3
RAKES
4
E4
FIELDS
E2
G

90. Auxiliary Fingers.—In the center of the space that the drawing devotes to the power part of the main drum are four fingers R_1, R_3, $D R$, and *34*. These fingers being independent of the main-drum fingers proper and not being in line with them vertically, but being in line with them horizontally, can make contact with one part of a drum tip, while one of the drum fingers proper is resting on another part of the same tip. For example, on the first power notch, main finger B makes contact with tip $B D_1$ at the same time that auxiliary finger $D R$ makes contact with its mate $B D_1$. The object and action of these auxiliary fingers will be taken up later.

91. The Reverse Drums.—The *reverse drum proper*, which is used to reverse the direction of motion of the car, is in the top right-hand corner of the drawing. This reverse drum is the one found on all up-to-date controllers, whether they control electric brakes or not, and interlocks with the main drum in the usual way. On this controller, there are two rows of reverse fingers, each row handling two motors. At the bottom of the controller development, under the main drum, are shown two auxiliary drums, which we will call the *generator reverse drums*, because their object is to keep the armatures of the motors of such polarity that they are connected to generate when the electric-brake connections are in use. The drum on the left is coupled directly to the shaft of the main drum, and so turns in the same direction as and with the main drum; the reverser drum on the right gets its motion through the agency of a gear on the main-drum shaft, and so turns in a direction opposite to that of its mate and the main drum; both of the generator reverse drums, then, are operated by the main drum, without extra precaution on the part of the motorman, and are operated in opposite directions. Each of the generator reverse drums has a neutral position and a row of fingers of its own. Each row of fingers is reproduced on the drawing to facilitate tracing out current paths. Under normal conditions, when the car is going "ahead" and the brake is "off,"

the fingers *16*, *8*, *17*, *18*, F_1, *20*, on the left-hand drum, and fingers *15*, *14*, *13*, *12*, R_7, *11*, on the right-hand drum, rest on the long strip portions of their respective drums and remain so connected throughout the power positions of the main drum. The current from the trolley passes through the armatures of the car motors in a certain direction.

92. When the motorman throws his power handle to the off-position and continues it in this direction to the first brake notch, the fingers of the two generator reverse drums leave the long strip portions of their drums, pass to the short strip portions, and remain there throughout the six brake positions, thereby so connecting the motor armatures that they can generate.

93. Power Positions.—The power positions are indicated by the row of figures from *1* to *12*. On the first position, fingers T, R_2, *8*, *34*, B, and DR make contact (we will not consider B and DR for the present) on the main drum; all the fingers on the lower drums make contact, excepting *35* and *8*; the reverse switch is "ahead." The current path is through trolley–T–blow coil T_1–finger $T–PA_1–PA_1–R_2$ through the resistance coil to $R_7–R_7–R_7–R_7–R_7$ to finger *15* on the right-hand generator reverser–*28*$\left\langle \begin{matrix} A_1–AA_1–12–12–13–F_1–E_1 \\ A_3–AA_3–11–11–11–14–14–F_3–E_3 \end{matrix} \right\rangle E_1–$ $E_1–E_1–34–PC_3–PC_3–PC_2–8–8–8–20–20–20–20–23\left\langle \begin{matrix} A_2–AA_2– \\ A_4–AA_4– \end{matrix} \right.$ $\left. \begin{matrix} 17–17–17–17–17–17–18–18–18–F_2–E_2 \\ 16–16–16–16–16–F_4–F_4–F_4–F_4–E_4 \end{matrix} \right\rangle G$. The current path on the first notch is indicated by the arrowheads. It starts at the trolley; when it gets to reverse finger *28*, it splits, the current dividing between the No. 1 and No. 3 motors; the two currents reunite and flow as one to finger *23*, where they split again through the Nos. 2 and 4 motors, reuniting at E_2 or G, the ground wire. On the second position, the current path is the same except that finger R_4 cuts out two sections of resistance. On the third notch, R_5 cuts out another section, and on the fourth notch the remaining sections are cut out by finger R_7 and T making direct

connection through tips PA_4 and PA_1. Upon all the positions just considered, the motors are in series-parallel.

94. Brake Positions.—To operate the brake, the handle is moved backwards from the off-position. To follow the combinations, it is easier to conceive of the main-drum tips moving towards the row of fingers reproduced on the right. It is also simpler to imagine the short tips of the two generator reverse drums to move towards the row of fingers nearest to them, as these two auxiliary drums turn in opposite directions. When the controller drum is moved backwards one notch, all the auxiliary drum fingers engage the tips under the word "brake" and continue to do so throughout the brake positions of the main drum. Main-drum fingers E_1 and G connect through tip BD_1; fingers B and R_1 connect through tips PA_3, BA_4, and BA_1. It will be noticed that finger B is the same distance from tip BA_1 that finger R_1 is from tip PA_3, so that when all the tips move to the right, those two fingers engage their respective tips at the same time. When the generator reverse-drum fingers pass from the long drum tips to the short ones, the armature connections of all the motors are reversed, thereby connecting the motors to act as generators. Consider armatures Nos. 1 and 3; while the long strips on the right-hand drum are in action, R_7 connects through *15* and reverse fingers *28* to A_1 and A_3, while AA_1 and AA_3 connect by way of *12* and *11* to fingers *13* and *14*. When the short strips are in action, A_1 and A_3 connect to *13* and *14* and AA_1, AA_3 to R_7.

95. Starting at finger *15* at the top of the right-hand reverser drum, we will trace a path to ground in both directions. To the right, the path is $15 \begin{array}{l} 28-A_1-AA_1-12-12-R_7 \\ 28-A_3-AA_3-11-11-11-R_7 \end{array} R_7$; $R_7-R_7-R_7-R_7-R_1-PA_3-PA_2-BA_4-BA_1-B-B_1-B_2-B_3-B_4-M-M_1-M_2$–brakes—to the ground at G. To the left from finger *15*, the path is $15-\begin{array}{l} 14-14-F_3-E_3-E_1-E_1-E_1-E_1-BD_1-G \\ 13-13-F_1-E_1-E_1-E_1-E_1-BD_1-G \end{array} G$. The No. 2 and No. 4 motors have one end of their field

grounded at E_4 and E_2. Tracing the circuit back, the double path is $G-\left\langle\begin{array}{l} E_2-F_2-18-18-18 \\ E_4-F_4-F_4-F_4-F_4 \end{array}\right\rangle-20-20-20-20-\left\langle\begin{array}{l} 23-A_2-A\,A_2- \\ 23-A_4-A\,A_4- \end{array}\right.$
$\begin{array}{l} 17-17-17-17-17-17 \\ 16-16-16-16-16 \end{array}\Big\rangle 8-8-8-R_7-R_7-R_7-R_7-R_7-R_1-P\,A_3-P\,A_2-$
$B\,A_4-B\,A_1-B-B_1-B_2-B_3-B_4-M-M_1-M_2-$brakes$-G$. All four motors have both ends grounded, and are therefore in multiple. No change is made after the first brake notch, except that resistance is cut out successively by fingers R_2, R_4, R_5, and R_7.

96. Fig. 80 is a simple sketch showing the connections of the motors, plugs, blow coil, overload switch, and brakes. The action of the overload switch is as follows: The magnet coil carries the braking current of all the motors; if this current exceeds a certain predecided value, magnet M pulls

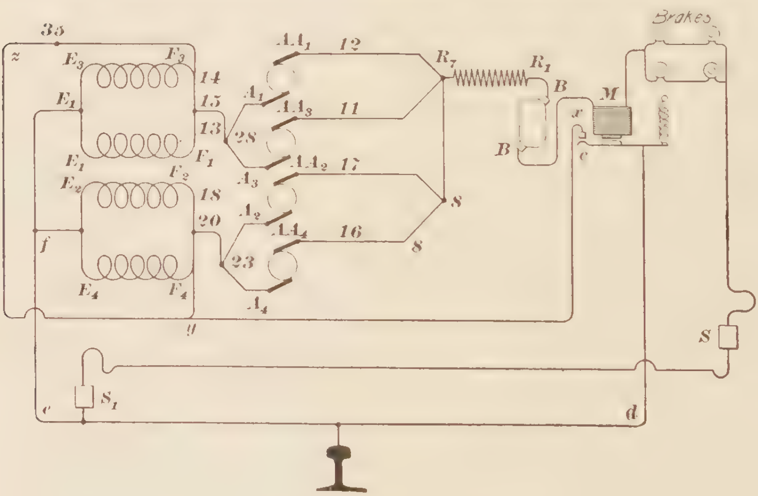


FIG. 80.

on its armature, thereby causing contacts c and x to touch, bringing together wires $x\,y\,z$ and $c\,d\,e\,f$; wire $x\,y\,z$ connects to one end of all the motor fields and wire $c\,d\,e\,f$ to the other end, so that when they touch, the motor fields are all short-circuited, depriving the motors of their ability to generate. As soon as this happens, magnet M releases,

opening the short circuit and allowing the fields to build up again.

97. Releasing Brakes.—Full release of the brakes is accomplished by passing a demagnetizing trolley current through the brake coils. This operation is performed through the agency of finger DR and tips BD_1, Fig. 79. The resistance between fingers DR and R_1 is called the *demagnetizing* resistance, because it limits the strength of the demagnetizing current. The resistance is about 60 ohms. The demagnetizing current need be but very small, as the demagnetizing effect is helped considerably by the vibration incidental to the starting of the car. On the first power position, finger B engages one BD_1 tip and finger DR the other, so that on this position current from the trolley wire takes path: trolley–T–T–T_1–T–T–PA_1–PA_1 to finger R_2; here the current splits, part taking the path through the *power* part of the resistance to R_7 and thence to the motors, and part taking the path through the brake part of the resistance to finger DR, thence through path DR–BD_1–BD_1–B–B_1–B_2, etc. to the brakes. This trolley current passes around the brake coils in the opposite direction to what the braking current passed and so destroys the residual magnetism sufficiently to release the brakes.

98. An Exceptional Condition.—In ordinary applications of the brake, it is, of course, only necessary to throw off the power and to continue in that direction to the brake notches, the generator reverse drums tending to the reversal of connections ordinarily accomplished with the reverse switch proper on cars not equipped with electric brakes. In case, however, a car is ascending a hill and the blowing of a fuse causes it to start to roll backwards, the *direction* of *rotation* of the armatures has been reversed, so that their connections need not be; but the act of putting the power handle on a brake notch *has reversed* the connections. With the direction of rotation and armature connections *both* reversed, the motors *cannot* generate. Under such a condition, then, throw the reverse switch proper before putting the controller handle on a brake notch.

WESTINGHOUSE ELECTRIC BRAKE.

99. The Westinghouse electric brake also makes use of the generator action of the motors; but the brake itself differs considerably from the General Electric brake. The Westinghouse brake acts on the regular brake shoes and in addition also operates a pair of shoes that press on the track between the truck wheels. Fig. 81 shows the general arrangement of the brake. *a*, *a'* are the track shoes and *b*, *b'* the regular brake shoes. When not in use, the brake hangs suspended by springs *d*, *d'* a short distance from the rail; *c* is the magnetizing coil supplied with current from the motors running for the time being as generators. When current is sent through *c*, the shoes are pulled down against the track.

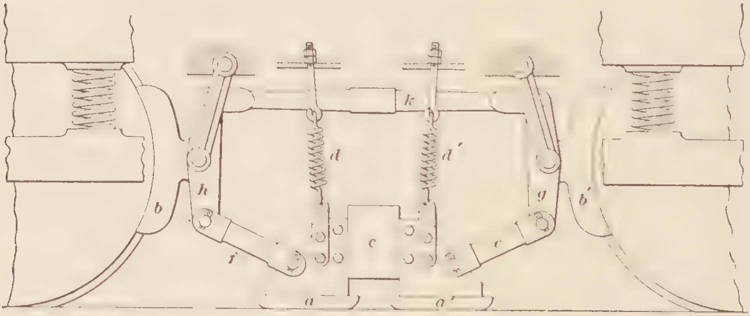


FIG. 81.

At the same time, the drag caused by shoes *a*, *a'* causes the regular brake shoes to be pressed against the wheels through the agency of the levers *e*, *k*, *h*, *f*, thus exerting a powerful braking action.

In the Westinghouse electric-brake system, the connections are arranged so that either the regular car starting resistance or the electric car heaters may be used as the controlling resistance for the brakes. By using the heaters in winter for the brake controlling resistance, a considerable saving is effected, because the current for the heaters is then supplied without drawing on the power station. In other words, heat is used that would otherwise be wasted.

THE MULTIPLE-UNIT SYSTEM.

100. The multiple-unit system is not intended for ordinary street-railway service, but is intended for the operation of trains ordinarily handled by steam engines. A single car with its full equipment for heat, light, brakes, and motive power constitutes a single unit; several such units coupled together into a train, with the proper provision made so that the motors on all the cars can be operated simultaneously from the platform of any car, constitute a multiple-unit train.

101. Suppose we take three ordinary surface trolley cars completely equipped, and that instead of running the car wires from controller to controller on each car and letting them end there, we run the wires from end to end, tapping off to each controller and putting suitable couplers on the ends, as indicated in Fig. 82, so that the car wires on one car can be made continuous with those on the car next to it;

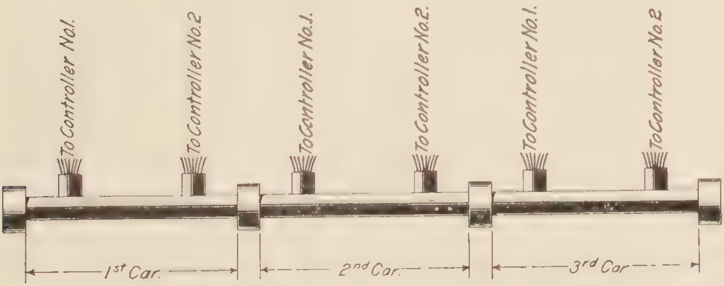


FIG. 82.

then we will have a three-car train. The main-current motor wires will run from one end of the train to the other, irrespective of the length of the train; the train can take the current from one trolley pole or from all the poles at once, and it can be operated from any one controller on any car, whether it is in the middle or on the end. Every car will do its own share of the work, so that the whole train will start, run, and stop as quickly as a single car. This will

be a **multiple-unit system;** but there are several strong objections to the adoption of such a system. In the first place, there would be continual trouble with any single controller that would be called on to handle the current of more than two cars. Next, the car wiring would have to be extra heavy, as the wires on the end car, if the train were to be operated from that car, would have to carry the current of all the cars. Again, it would be almost impossible to devise a practicable coupler that would handle such heavy currents without giving continual trouble. Finally, in case of complications arising due to short circuits or grounds on the car wires of any car, the cut-out device that would meet all conditions would have to be very elaborate. These objections have been met and almost entirely overcome by the three multiple-unit systems now on the market. The essential feature of all these systems is that each car is a self-contained unit as far as the main-motor circuit is concerned.

102. On all the systems there is placed upon each platform of every motor car a small controller, called the *master controller*. In no case does this master controller take up over a cubic foot of space. Every car has what is called a train line; the wires running to the master controllers are done up in a small cable provided with couplers on the ends, just as shown in Fig. 82. The wires themselves and the currents that they carry are small, so that none of the troubles incidental to arcing, heating, or burning are encountered. When the train is made up, the train line extends from one end to the other, connecting all the master controllers and the mechanisms that they operate, so that all the main-circuit controllers and hence motors can be operated from any master controller on the train. It must be understood that the master-controller circuit is entirely distinct from the main-motor circuit and is just as free from liability to troubles as an ordinary lamp circuit. The master controller has a series and a multiple position, and it can be seen that it is extremely important that the

main-controller operating devices should respond to the notches of the master controller with precision; for if the main-motor controllers should feed up at different rates, a condition might arise where the motors on some cars would be in series and those on other cars in multiple, thus producing a very bad state of affairs. This feature is taken care of by a synchronizing device that not only makes the main-motor controllers notch at the same rate, but also makes the cylinders notch with precision and with a springy centralizing motion that prevents the hanging of an arc.

Every car is provided with an electromagnetic throttle that stops the pilot motor or other device that runs the main-motor controller should the current for any reason exceed a predetermined value, based on the capacity of the motors, the traction of the wheels, and the rate of acceleration desired. The whole equipment is so balanced that the proper acceleration falls within the limit imposed by setting the throttles to work just below the slipping point of the wheels when the car runs light. The throttle makes it practically an impossibility for a motorman to abuse the motors, even should he handle the master controller recklessly. The main controllers can be put under the car, on the platform, under the hood, or inside the car under the seats, if there is room for them.

103. Air Brakes on Multiple-Unit Cars.—Each car has its own air-braking outfit, consisting of a motor-compressor governor, triple valve, tanks, etc., so that if called upon to run alone, it can do so. Simultaneous starting and stopping of the air pumps is accomplished by means of a balance wire running the length of the train and connecting all the junctions of the motor compressors and their governors. Each of the governors is actuated by pressure from the main reservoir, and all these are connected by a balance pipe running the length of the train, so that all compressors are started or stopped by the weakest governor in the lot. The compressor on any car can be cut out, its tank being kept filled by the others. It can be seen that each car is

absolutely an independent unit. The advantages of the system in heavy train work are many, and it is destined to fill a large field in the near future. Trains can be split up, shifted, and housed without the aid of any outside source. It also has the advantage that instead of lengthening the intervals between trains in the quiet hours of the day, the time table can be kept the same and the trains themselves shortened, even down to running single cars. Where every car is a motor car, the starts are much smoother, there is no bumping or jerking, as each car starts itself and there is never much tension or compression on the drawbars, and the trains are not apt to break in two.

104. The multiple-unit system has, so far, been used mostly on elevated roads. The outfit is necessarily somewhat complicated, but notwithstanding this fact, it has given good service. The above description will give the student a general idea as to how the system is operated. The details of the different devices and connections are beyond the scope of this Course.

INTERIOR WIRING.

(PART 1.)

PRELIMINARY CONSIDERATIONS.

1. In the work of every artisan there are certain factors that must never be overlooked and certain conditions that must always be fulfilled before the final object of the work can be reached or even approached.

In electric wiring, the ultimate object is the conveying of the electricity to the lamp, bell, motor, or other device that is to be operated. But this must be done in a proper manner; otherwise danger, unsatisfactory operation, and waste are sure to result.

2. There are four things that should be considered in every electric installation. They are (*a*) safety, (*b*) satisfactory operation, (*c*) convenience and neatness, and (*d*) economy. The first of these considerations is by far the most important in all ordinary wiring. Therefore, the electrical artisan should understand, first of all, what are the sources of danger in the use of electric currents and then what precautions are necessary and what conditions must be complied with to avoid these dangers. When he thoroughly understands these things, he should learn how to make his work satisfactory in other respects and profitable to himself.

The same causes that, under certain conditions, make electricity dangerous to life also make it a source of fire hazard. There are also conditions under which an electric

For notice of copyright, see page immediately following the title page.

current may cause fire, although it may not be directly dangerous to life. In discussing the precautions necessary to avoid any chance of fire from an electrical cause, the student will learn how to avoid danger to life as well, so that it is unnecessary to discuss that subject by itself.

FIRES CAUSED BY ELECTRIC WIRING.

3. The so-called "electrical fires" or fires that are caused by the presence of electric wires or apparatus within a building can be divided into three classes, as follows:

(*a*) Fires caused by poor work or improper materials.

(*b*) Fires caused by overloading the apparatus or wire with a higher voltage or with more current than it was designed to carry.

(*c*) Fires caused by lightning striking the outside lines or by the crossing of circuits that should never come into contact with one another.

A good job of interior wiring overcomes all danger due to the first two of these sources of hazard and most of the danger due to the third, but not all, for accidents sometimes occur outside of the buildings, against the results of which the present accepted devices for the protection of inside circuits are not sufficient. The failure of a lighting company to use proper lightning arresters and transformers or to properly insulate the outside wires may cause trouble within a building where the wiring is properly done.

THE NATIONAL ELECTRICAL CODE.

4. When electric lights first came into general use, the insurance companies discovered that there were many fires of electrical origin, the wiring done on the first installations being of very inferior workmanship. The various associations of underwriters, therefore, formulated rules in accordance with which they required that all wiring be done or

they would not insure buildings containing it. In the course of time, these various rules of local associations were reduced to a uniform code, and finally, in 1898, they became known as the **National Electrical Code** and received the endorsement of practically all the inspection bureaus throughout the United States, besides that of the following organizations: the American Institute of Architects, the American Institute of Electrical Engineers, the American Society of Mechanical Engineers, the American Street Railway Association, the Factory Mutual Fire Insurance Companies, the National Association of Fire Engineers, the National Board of Fire Underwriters, the National Electric Light Association, the Underwriters' National Electric Association.

A few cities have rules of their own that differ slightly from this code, but the differences are not vital. Any person doing work in any city where there is municipal legislation governing his work should investigate the laws of that particular place before undertaking to lay out work for himself. Every wireman should be supplied with a copy of the latest edition of the National Electrical Code and do work in compliance with those rules, whether additional laws exist or not. Copies of the code and of all other information published by the Underwriters Association for the sake of reducing the fire hazard can be obtained by writing to the laboratories of the National Board of Fire Underwriters at Chicago or by applying at the nearest Underwriters' Inspection Bureau. The rules are revised by conventions as often as changes in the electrical art make such revision necessary.

5. In addition to this code of rules, the National Board of Underwriters publishes each year a **List of Approved Fittings** for use in connection with the code. This list contains the names of articles that have been found entirely satisfactory, together with the names of the manufacturers. It does not contain a list of *all* fittings that will pass inspection, and many good articles are not listed in its pages.

EXAMPLES OF ELECTRICAL FIRES.

6. That the student may properly understand the nature of the fire hazard due to the presence of electric circuits, before studying the various preventives, the following typical examples of electrical fires are briefly described. These are reports of actual fires and burn-outs taken from the Quarterly Fire Reports of the National Board of Fire Underwriters.

1. Loose connection on series-incandescent circuit in show window. Arc ignited insulating covering of wire and fire spread to surrounding inflammable material. Four sprinkler heads opened and extinguished the fire. Contents of window destroyed.

2. Socket-shell burn-out in show window of millinery store. Short circuit caused by metallic shell of socket on window fixture establishing connection between projecting strands of flexible fixture wire.

3. Paraffin-covered wire used for pendants for drop lights. Wiring installed on a motor circuit, after inspection, by occupant of building who wished to secure light. Short circuit ignited paraffin covering and whole place burned up.

4. Short circuit or ground on constant-potential lighting circuit, where mains ran unprotected through damp woodwork in a brewery. The arc formed ignited insulating covering of the wire and fire communicated to woodwork of frame building.

5. Short circuit in flexible cord in show window burned out the window.

6. Heating effect of incandescent lamp. A 16-candle-power incandescent lamp on a 52-volt circuit was left lying on an office coat in a newspaper office. About 4 hours after the lights were turned on the coat was discovered smouldering, and on being moved burst into flame.

7. Revolving wheel of incandescent lamps in show window covered with handkerchiefs burned out the window

either by sparking at the commutator or from heating effect of the lamps.

8. Sparks from an arc lamp dropped on a table underneath that was covered with open boxes of shirt waists. The table and contents destroyed, otherwise no considerable damage.

9. Flexible lamp cord wound around a gas fixture having a soft rubber insulating joint. The current grounded through the joint and the arc ignited the escaping gas.

10. Overheating of No. 14 B. & S. wires due to partial short circuit, caused by moisture, through porous crockery knobs on which wires were mounted. The fuses, which were too large, did not melt for some time and the burning insulation of the wires set fire to combustible material near, causing a loss of $15,000.

11. A fuse block, improperly constructed and placed in close proximity to woodwork, held an arc after a short circuit long enough to set fire to the woodwork.

12. Main feed-wires placed in an elevator shaft were short-circuited by a breakdown of their insulation. A heavy arc was established that set fire to building.

13. Overheating of resistance coil of arc lamp that was improperly insulated and too near adjacent woodwork set fire to building.

14. Short circuit of No. 14 wires installed, contrary to rules, in molding in a place exposed to moisture. The fire was stubborn and burned fitfully between floors and was not extinguished before a loss of $2,000 had been sustained.

15. Fire in public institution. Building wired throughout with weather-proof wire run through joists without bushings, both wires of the circuit being brought through one hole at lamp outlet without separation. Short circuit occurred in attic that quickly set fire to dry timbers.

16. An Edison plug cut-out was improperly used to protect a 5-horsepower motor operating at a difference of potential of 220 volts. Fuse in blowing failed to open circuit, thus maintaining an arc that set fire to building.

17. Circuit controlling an electric flat iron was left turned on, becoming overheated and setting fire to the table. Circuit had no signal lamp or other indicating device recommended for such equipment.

18. Overheating of mechanism in a 2,000-candlepower series-arc lamp, the metal casing of which did not fit, set fire to the ceiling. The store was closed, but the lamp had been left burning until the circuit was shut off. This fire illustrates the advisability of cutting all current out of buildings when the same are unoccupied.

19. A fire occurred in show window, caused by a bath towel falling from support on to a lighted incandescent lamp in bottom of window; the towel becoming ignited set fire to the contents of window and damaged some of the stock in store.

20. Lightning entered building over badly installed watchman circuit. No protective devices at entrance to building. Wires badly insulated, fastened by staples. Heat of wires set fire to joists of building.

21. Ground of 110-volt circuit on gas pipe in attic. Arc burned $\frac{1}{4}$-inch hole in pipe and set fire to escaping gas.

22. Fire in basement of building caused by accumulation of sodium salt on back of three-wire molding run on brick wall. Trouble occurred at a point where a nail had been driven through molding into wall.

23. Short circuit in fixture canopy ignited ceiling above fixture. Fire also occurred at same moment in cabinet at center of distribution. It was found on inspection that the branch cut-out contained copper wire.

24. An ignorant workman installed a lighting circuit in lead-covered cable, fastening same to iron ceiling with staples. Breakdown of insulation of cable set fire to ceiling, when it was found that no main switch had been installed and current could not, therefore, be cut off.

25. Switch on electric-light circuit was mounted in dry-goods store at a point where draperies came in contact

with it. Flash from same ignited draperies and fire spread rapidly to millinery and other inflammable material.

26. Breakdown of insulation on wires of lighting circuit in a fine residence set fire to woodwork inside partitions. Fire occurred at night, and owing to delay in sending in alarm and the distance from fire-department headquarters, fire was not extinguished until a heavy loss had been sustained.

27. Electric-light wire sagged and made contact with telephone wire running to cable box. Box and cable connections completely destroyed.

28. Burglar-alarm, electric-bell, and electric-light wires came together inside the partitions of a residence. The insulation on the wires was ignited and followed up the partitions. Owing probably to lack of oxygen, fire did not break out of partitions, but spread so generally over the house inside that much damage had to be done before it could be extinguished.

29. Circuits were run in circular loom tubing immediately over a steel ceiling. Where the tubing came through the ceiling for a loop, the sharp edges of the ceiling cut through the same, short-circuiting the wires. Arc ignited the insulation of the wires, fire following same up under the ceiling.

30. Fire in livery stable due to blowing of fuse in uncovered cut-out into straw. Fire spread so rapidly that it was impossible for the department to control it.

31. Fire in basement of hotel caused by water leaking and running down the blades of a switch on 500-volt circuit.

32. Serious burn-out of fire-alarm system by cross on 500-volt feed wires of an electric railroad. Nine fire-alarm boxes, a tapper, and an indicator were burned out, the repeater also being partially destroyed. Fire was also started in the residence of the chief of the fire department, but was promptly extinguished. It was found on inspection that the instruments were protected by fuses that were much too short.

7. Figs. 1 to 6 illustrate some characteristic burn-outs; they have been drawn from photographs of burn-outs that have actually occurred.

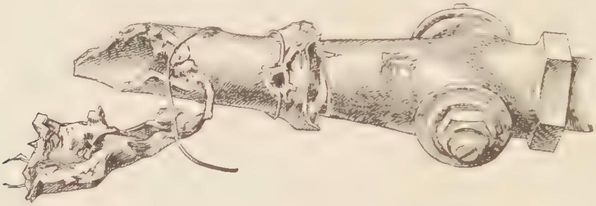


FIG. 1.

Fig. 1 shows a gas pipe that was melted by an arc caused by a heavy current-carrying circuit crossing a signal circuit that was connected to the pipe. The connection to the pipe was poor and unsoldered.

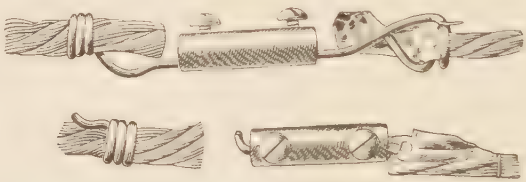


FIG. 2.

Fig. 2 shows joints made with No. 10 wire on a circuit designed to carry 200 amperes. The use of such a poor joint gave rise to heating that resulted in the burning out of the wire.

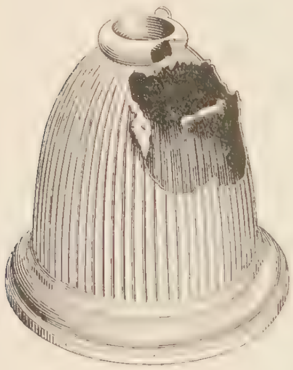


FIG. 3.

Fig. 3 shows a fixture canopy with a hole melted through it, caused by a fixture cut-out inside the canopy becoming short-circuited.

Fig. 4 shows a burn-out caused by a short circuit between weather-proof wires used in molding. Wire with weather-proof insulation only should never be used in molding,

and its use in molding is prohibited by the Underwriters. Figs. 3 and 4 are from photographs by Mr. Wm. T. Benallack.

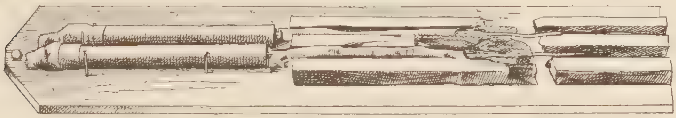


FIG. 4.

Figs. 5 and 6 show burn-outs caused by short circuits in cut-outs. The burn-out in Fig. 5 was due to defective design, the two sides of the circuit being brought so close together that when a fuse melted the arc held over and destroyed the cut-out.

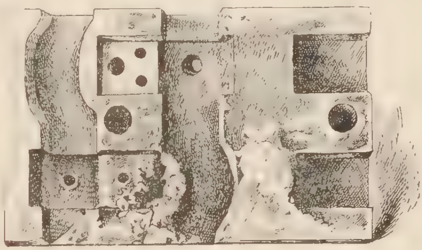


FIG. 5.

In Fig. 6, the cut-out was placed horizontally. When the fuse melted, the metal ran down and established

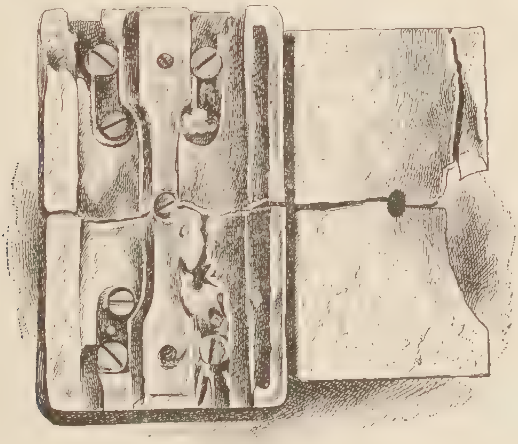


FIG. 6.

connection between the lines, thus resulting in a short circuit.

ELECTRIC LAMPS.

INCANDESCENT LAMPS.

8. Before taking up the subject of wiring for electric lights, it will be well to look briefly at some of the characteristics of the lamps to which the wiring is to supply current, as the requirements of the lamps have a considerable influence on the character of the wiring. **Incandescent lamps** are the ones mostly used for interior illumination, so we will briefly consider a few of their characteristics. The selection of good lamps of proper voltage, candlepower, and efficiency to suit the work for which they are to be used is a matter of great importance.

The light-giving part or **filament** of an incandescent lamp is of carbon, being generally made of carbonized cellulose thread. Its manufacture has been the subject of much research by the large manufacturing companies, which keep the details as secret as possible. A good lamp filament must be uniform in cross-section, density, and resistance per unit of length. It must also be manufactured with special reference to the voltage and current with which it is to be used.

9. The filament is mounted on the ends of **leading-in wires** of platinum, which pass through a glass neck or stopper. The outer ends of these platinum wires are soldered to copper wires that are connected to the proper parts of the lamp **base** when all the other work on the lamp is finished. The shell of the lamp base is filled with plaster of Paris, which holds the lamp firmly in place.

10. The connecting of the filament to the leading-in wires is usually done with a carbon paste and is an important operation, for the lamps and filaments frequently break at this point.

11. The lamp **globe** surrounds the filament and is airtight. All the air within it is exhausted to a very high degree. The exhaustion is important in all lamps and

must be done with extra care for high-voltage lamps, or the current will "arc" across the ends of the leading-in wires and destroy the lamp.

12. Even the highest grades of incandescent lamps are not very long-lived. They may burn for years without having the filament break, but they will not burn at their proper efficiency or candlepower. The light is produced by the carbon being heated to a very high temperature. No known solid substance can be maintained at a temperature of very brilliant incandescence without undergoing a change in its physical properties. This is true of carbon, as of all other materials. The heat alters its density, resistance, and other properties. The higher the temperature, the more rapid is the physical change. Some of the properties lost by heating to high temperatures are regained upon cooling, but others are not. Among the limitations to carbon incandescent-lamp filaments, those in regard to size are very important. Below a certain minimum diameter and above a certain maximum carbon filaments are not practicable.

13. When an incandescent-lamp filament is heated beyond a certain limit, it rapidly deteriorates, giving off gaseous particles that condense on the globe and blacken it. If the heating is very sudden, the filament explodes and may break the glass.

Carbon being highly inflammable when very hot, the air must be exhausted from the lamps. But if only the oxygen were removed, the student may suggest, the lamps would burn satisfactorily. It is true that in that case the filaments would not burn, but the gas within the lamp would become very hot and expand and burst the globe; or if the globe did not break, it would become as hot as the gas within it. Incandescent lamps with the air only partially exhausted are not practical devices, though many have tried to make such.

14. In incandescent-lamp practice, it has been found by experience that the best results are obtained when lamps are

burned at a certain temperature for about seven hundred hours. They may be burned at a lower temperature for a longer time, but give less light; or at a higher temperature for a short time, giving more light. It is very poor economy to burn lamps after they have become dim, for they take about as much current as new lamps and give very little light in return. What is wanted is the most light for the least money, taking into account both the cost of current and the cost of renewing lamps.

The effect on a lamp of altering the voltage only a slight amount is much greater than is commonly supposed. By a study of Table I, which is given by the General Electric

TABLE I.

EFFECTS OF CHANGE IN VOLTAGE IN STANDARD 3.1-WATT LAMP.

Voltage. Per Cent. of Normal.	Candlepower. Per Cent. of Normal.	Watts Per Candlepower.	Life. Per Cent. of Normal.	Deterioration Per Cent. of Normal.
90	54	4.63	941	11
91	58	4.41	716	14
92	62	4.21	555	18
93	66	4.04	435	23
94	70.5	3.89	345	29
95	75	3.74	275	36
96	80	3.59	220	45
97	85	3.46	179	56
98	90	3.33	146	69
99	95	3.21	121	83
100	100	3.10	100	100
101	106	3.00	82	122
102	112	2.91	68	147
103	118	2.82		179

Company, it will be seen that at the prices for which lamps sell (about 18 to 25 cents each for a 16-candlepower lamp) it is not economical to burn lamps more than their proper life, and it is of the utmost importance that the voltage be uniform and correct. If the voltage be absolutely steady, lamps may advantageously be burned a volt above their marked voltage and used a correspondingly shorter time. But the advantage is doubtful unless the greatest care is exercised in renewing lamps. The table shows that, for the lamps tested, an increase of 3 per cent. in voltage increases the light 18 per cent., but increases the deterioration 79 per cent. On the other hand, with a voltage 10 per cent. lower, the light is cut about in half, but the life is extended indefinitely. It is to the manufacturer's interest to mark lamps at the most suitable voltage, but poor lamps are often improperly marked, causing a waste both of current and lamps when they are connected in the sockets. Some manufacturers do this false marking to dispose of lamps of odd voltages for which they have no market. "Job lots" are apt to be of this kind, as are all lamps not marked with the manufacturer's name.

15. Incandescent lamps are made of different efficiencies. The most efficient ones should be used where absolutely constant potential is employed, the less efficient ones where the voltage is somewhat unsteady. Fifty- to 125-volt lamps are made to consume from 3.1 to 5 watts per candlepower, according to the grade and the size of the lamp. Good 200- to 250-volt lamps consume about 4 watts per candlepower. Up to the present time it has been found impracticable to make high-voltage lamps more efficient, owing to the fineness and the length of the filament and other difficulties that rapidly increase when the voltage is increased. Generally speaking, the lower the voltage the easier is the manufacture of filaments.

16. Good lamps, when the glass is clean and when they are placed so that the light can freely leave them, do not get very warm; but if something be placed against the

globe so that the heat cannot get away, the lamp soon becomes very hot—hot enough to set fire to dry goods in show windows, for instance. Also, lamps get hot if they are dirty, or if they have not been properly exhausted.

17. The most perfect exhaustion is essential in high-voltage lamps. A globe exhausted to a considerable degree, but not enough, will show a blue brush discharge between the terminals of the leading-in wires. While the insulating properties of air at atmospheric pressure or of a vacuum are very good, those of rarefied air are poor. In a 220-volt lamp not properly exhausted, the current will strike across the space between the leading-in wires, make a short circuit, and cause the lamp to explode. If lamps get hot, they should first be wiped clean. If they still get hot, they should be removed and destroyed.

18. From the foregoing, then, it will be seen that it is very important to so plan all incandescent-lamp wiring that the lamps will get the voltage for which they are designed. If the voltage is too high, the lamps will give a good light while they last but they will soon burn out. On the other hand, if the lines have such a resistance that it takes a considerable portion of the pressure supplied to force the current through them, the voltage at the lamps will be low and the light very poor and unsatisfactory.

19. Operation of Incandescent Lamps.—Incandescent lamps are operated on constant-potential (pressure) systems. By this is meant that a constant electrical pressure or voltage is maintained between the supply wires by the generator at the station. In practice, the value of the supply voltage may vary a little, but if the station is properly operated, it should remain practically the same no matter how many lamps are in use. The lamps have a high resistance (about 220 ohms for an ordinary 16-candlepower 110-volt lamp when burning) and are connected directly across the lines. Incandescent lamps are, therefore, operated in **parallel**, as will be illustrated more fully later. Each lamp has a

fixed resistance, and as the voltage of the supply is fixed, it follows that each lamp will take a current dependent on its own resistance independently of the current taken by the other lamps. For example, a 110-volt 16-candlepower lamp will take about ½ ampere of current, and each lamp turned on will require ½ ampere, so that as the number of lights in use is increased, the current in the main-supply wires increases but the voltage remains practically unchanged. When lamps are operated in parallel, it is evident that any lamp may be turned on or off without interfering with the current supplied to the other lamps. The voltage supplied to the lamps is usually between 100 and 115 volts, constituting what is called a **low-potential system.** In former years, a pressure of 52 volts was commonly used on alternating systems, while in recent work lamps for 220 volts are being used to some extent. A 16-candlepower lamp requires about 55 watts, and on a 110-volt circuit this means ½ ampere. For approximate wiring calculations the following values (Table II) of the current for different kinds of lamps may be used. It must be remembered that these values are not rigidly fixed, because lamps are made for a number of different efficiencies and current consumption.

TABLE II.

POWER CONSUMPTION FOR INCANDESCENT LAMPS.

Candlepower.	Voltage.	Current. Amperes.	Watts.
8	110	.27	30
10	110	.32	35
16	110	.50	55
16	52	1.00	52
16	220	.30	66
32	110	1.00	110

ARC LAMPS.

20. Arc lamps are now used much more extensively for interior illumination than they were a few years ago. This is due to improvements in the lamps that make them much better suited to this class of work. Arc lamps used on interior work are usually operated in multiple in the same way as incandescent lamps. For many years **open-arc lamps** (i. e., those with the arc exposed to the air) were operated on 110-volt circuits by operating two of them in series across the lines. A small amount of resistance was used in series with these lamps to improve the regulation and to take up the voltage over and above that required by the two arcs. Forty or 45 volts were consumed at the arcs and 20 to 30 volts in the resistance, and the lamps usually required about 10 amperes. But since 1895, **enclosed-arc lamps** have come into very extensive use, displacing the old, low-tension, open-arc lamps almost altogether and taking the place of clusters of incandescent lamps, and also, to a very great extent, of series-arc lamps used in interior lighting.

It was found that by using purer carbons than had been the practice formerly and by enclosing the arc in a small globe, so that free air could not reach it to burn the carbons rapidly, as in the open arc, the voltage at the arc could be increased to 70, 80, or 90 volts and the current reduced to 4 or 5 amperes.

21. In open arcs, the light is produced almost entirely on the positive, or upper, carbon surface, and the combustion of the carbon vapor produced at the arc is essential to the operation of the lamp. In enclosed arcs, a large amount of light is produced in the arc itself, which is from $\frac{1}{2}$ to $\frac{3}{4}$ inch long.

Not only is it possible to produce these long, high-voltage arcs, but it is necessary to have an arc of at least 70 volts, if it is well enclosed. Shorter enclosed arcs decompose the carbon of the positive pole and deposit it in the form of lamp-black on the negative one, thus obscuring the light altogether.

In an enclosed-arc lamp only the highest grades of carbons can be used. Cheap carbons cause flickerings and very rapidly discolor the glass enclosing globe, but the lamps burn from 100 to 150 hours (according to the current used, about 150 hours on 4 amperes), thus being more economical in the use of carbons than open arcs of the same watt capacity, which burn the same amount of carbon in 8 or 10 hours. The light from the enclosed arc is much softer and steadier than that from the old style open arc and has come to be generally considered the proper light for general interior lighting in large establishments and public buildings.

22. The long arc gives a large percentage of violet-colored rays that are not pleasing to the eye and which add very little to the illumination. The inner and outer globes of these lamps should have a slight "alabaster" coloring, which destroys the disagreeable rays. But it must be a very slight coloring, or it will absorb too much good light as well. Opalescent globes should not be used with arc lamps. They increase rather than diminish the objectionable qualities of the light and make the lamp appear to be burning more unsteadily than is actually the case.

23. Satisfactory enclosed-arc lamps are produced for alternating currents. The earlier alternating-current arc lamps were very objectionable on account of the noise produced—a continual, penetrating hum; but lamps of later patterns with long arcs and two enclosing globes are almost noiseless.

24. In wiring for low-potential arc lamps on continuous-current circuits, it should be remembered that these lamps require a resistance in series with the arc in order to regulate properly. The drop through this resistance is about 30 volts out of 110. Usually it is adjustable and is placed within the structure of the lamp, so that the lamp can be made to burn well on any circuit of from 105 to 120 volts. Since some 30 volts must be lost in any event, there is no need of running large-size wires from the mains to the lamps to avoid the drop, as the resistance in these wires can be used

as a portion of the required resistance and the lamp adjusted accordingly. The drop must be in the individual lamp circuit, not in the mains, where it would have no regulating effect, but would be a disadvantage.

Enclosed-arc lamps are made to burn either singly or two in series on 220-volt circuits. Those designed to burn two in series must be procured in pairs adjusted to burn together, otherwise they work poorly, give uneven light, "seesaw," one lamp taking most of the power for a while, and then the other, or refusing to work at all.

When burned singly on 220 volts, the lamp works satisfactorily, but it is not as efficient as lamps of a lower voltage. A 220-volt enclosed-arc lamp consumes about 130 volts at the arc and 90 in the resistance. It requires 2½ amperes, or more, and gives a little less light in proportion to the power it takes than is given by 110-volt lamps. Single 220-volt lamps are a convenience, however, in places where one lamp only is desired and other current cannot be secured. They are far more economical as light producers than 220-volt incandescent lamps. A 110-volt lamp usually takes from 3 to 6 amperes; 5 amperes is a fair average.

25. Enclosed-arc lamps for alternating currents are quite simple to operate and are efficient. While the arc itself does not give as much light as an 80-volt continuous-current arc of the same watts input, there is not so much power lost in artificial resistance for regulating purposes.

GENERAL RULES.

26. In wiring for electric lights and power, there are certain rules that apply equally to all systems and voltages. These rules will be our first study. In what follows, rules taken from the National Electrical Code are printed as below to distinguish them from the explanations and other matter. In most localities these rules have the force of laws.

GENERAL RULES—ALL SYSTEMS AND VOLTAGES.

Copper for insulated conductors must never vary in diameter so as to be more than $\frac{2}{1000}$ inch less than the specified size.

Wires and cables of all kinds designed to meet the following specifications must be plainly tagged or marked as follows:

1. The maximum voltage at which the wire is designed to be used.

2. The words "National Electrical Code Standard."

3. Name of the manufacturing company and, if desired, trade name of the wire.

4. Month and year when manufactured.

Wires—

a. Must not be of smaller size than No. 14 B. & S., except in fixtures and flexible cords. This is because wires of smaller size are likely to break or become loose, so that the work does not remain mechanically secure, and because a small wire is much more likely to be overloaded by connecting a few additional lamps to it than is a larger wire.

b. Tie-wires must have an insulation equal to that of the conductors they confine.

c. Must be so spliced or joined as to be both mechanically and electrically secure without solder; they must then be soldered to insure preservation, and the joint covered with an insulation equal to that on the conductors.

Stranded wires must be soldered before being fastened under clamps or binding screws, and when they have a conductivity greater than No. 10 B. & S. copper wire, they must be soldered into lugs.

All joints must be soldered, even if made with some form of patent splicing device. This ruling applies to joints and splices in all classes of wiring covered by these rules.

27. Whenever possible to avoid making joints, it is advisable to do so; but where joints are necessary, great care must be taken to do the soldering well, and to leave no

corrosive acid on the wire. There are several soldering compounds now on the market that will tin the wire well enough to make a good joint and yet leave no acid on it.

Soldering Fluid.—

The following formula for soldering fluid is suggested:

Saturated solution of zinc chloride................	5 parts.
Alcohol..	4 parts.
Glycerine...............	1 part.

28. Joints.—Figs. 7, 8, and 9 illustrate joints in common use. In removing the insulation from the wires where joints or connections are necessary, and in scraping the wire to clean it before making the joint, great care must be exercised not to cut into the wire and lessen its cross-section and, consequently, its carrying capacity. Especial care must be taken in handling fixture wires, which are small and easily cut or broken. A comparatively small nick in a copper wire will make it liable to break easily. In recovering the wire with insulating tape, a sufficient amount of tape must be used to afford ample protection. Where rubber-covered wires are spliced or joined, two kinds of tape must be used, the first of pure rubber softened by a volatile oil, and the second of cloth saturated with a moisture-proof adhesive material.

Fig. 7.

Fig. 8.

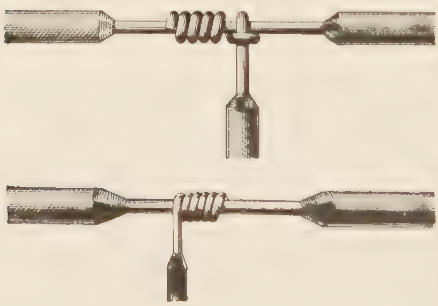


Fig. 9.

29. Rules Relating to Wires (Continued).—

Wires—

d. Must be separated from contact with walls, floors, timbers, or partitions through which they may pass by non-combustible, non-absorptive insulating tubes, such as glass or porcelain.

Bushings must be long enough to bush the entire length of the hole in one continuous piece, or else the hole must first be bushed by a continuous waterproof tube, which may be a conductor, such as iron pipe; the tube is then to have a non-conducting bushing pushed in at each end so as to keep the wire absolutely out of contact with the conducting pipe.

e. Must be kept free from contact with gas, water, or other metallic piping, or any other conductors or conducting material that they may cross, by some continuous and firmly fixed non-conductor, creating a separation of at least 1 inch. Deviations from this rule may sometimes be allowed by special permission.

f. Must be so placed in wet places that an air space will be left between conductors and pipes in crossing, and the former must be run in such a way that they cannot come in contact with the pipe accidentally. Wires should be run over, rather than under, pipes upon which moisture is likely to gather or which, by leaking, might cause trouble on a circuit.

Underground Conductors—

a. Must be protected, when brought into a building, against moisture and mechanical injury, and all combustible material must be kept removed from the immediate vicinity.

b. Must not be so arranged as to shunt the current through a building around any catch box.

This refers to catch boxes in the street, from which the wires should run to the buildings, and not from street to building, building to building, and back again into the street, around one or more catch boxes, thus shunting whatever protective devices there may be in the catch boxes.

TABLE III.

CARRYING CAPACITY OF INSULATED WIRES.

B. & S. Gauge.	Rubber-Covered Wires. Amperes.	Weather-proof Wires. Amperes.	Circular Mils.
18	3	5	1,624
16	6	8	2,583
14	12	16	4,107
12	17	23	6,530
10	24	32	10,380
8	33	46	16,510
6	46	65	26,250
5	54	77	33,100
4	65	92	41,740
3	76	110	52,630
2	90	131	66,370
1	107	156	83,690
0	127	185	105,500
00	150	220	133,100
000	177	262	167,800
0000	210	312	211,600
	200	300	200,000
	270	400	300,000
	330	500	400,000
	390	590	500,000
	450	680	600,000
	500	760	700,000
	550	840	800,000
	600	920	900,000
	650	1,000	1,000,000
	690	1,080	1,100,000
	730	1,150	1,200,000
	770	1,220	1,300,000
	810	1,290	1,400,000
	850	1,360	1,500,000
	890	1,430	1,600,000
	930	1,490	1,700,000
	970	1,550	1,800,000
	1,010	1,610	1,900,000
	1,050	1,670	2,000,000

30. Carrying Capacities of Wires.—As any wire carrying an electric current is somewhat heated, it is necessary to know how much current can safely be carried on a wire of a given size. The foregoing table (Table III) supplies this information.

Table of Carrying Capacity of Wires.—

The accompanying table (Table III), which must be followed in placing interior conductors, shows the allowable carrying capacity of wires and cables of 98 per cent. conductivity, according to the standard adopted by the American Institute of Electrical Engineers.

The lower limit is specified for rubber-covered wires to prevent gradual deterioration of the high insulation by the heat of the wires, but not from fear of igniting the insulation. The question of drop is not taken into consideration in the above table.

The carrying capacity of Nos. 16 and 18 wire is given, but no smaller than No. 14 is to be used, except as allowed for fixture work and flexible cord.

31. Wire Gauges.—It sometimes happens that wires of scant size are sold to the unwary. A workman constantly using wires of various sizes soon learns to gauge the size of wires by his eye, but it is better to use a wire gauge frequently to avoid mistakes. A wire of given size should just enter the slot intended for that size in the style of gauge shown in Fig. 10. Gauges in the form of a vernier caliper, measuring the diameter of the wire in **mils,** are usually more accurate. A **mil** is another name for a thousandth of an inch; for example, a

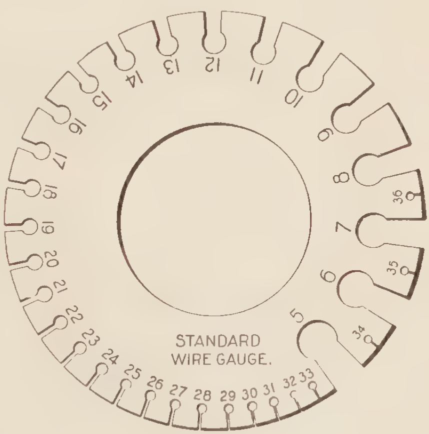


FIG. 10.

wire .18 inch in diameter has a diameter of 180 mils. When the diameter in mils is known, the gauge number can be found by referring to the table of dimensions of wires given in Table IV.

We are now ready to discuss the requirements of wiring for particular purposes, beginning with low-potential systems.

TABLE IV.

DIMENSIONS OF BARE COPPER WIRE B. & S. GAUGE.

Gauge Number.	Diameter. Mils.	Area. Circular Mils.	Gauge Number.	Diameter. Mils.	Area. Circular Mils.
0000	460.0	211,600.0	8	128.5	16,509.0
000	409.6	167,805.0	9	114.4	13,094.0
00	364.8	133,079.4	10	101.9	10,381.0
0	324.9	105,534.5	11	90.7	8,234.0
1	289.3	83,694.2	12	80.8	6,529.9
2	257.6	66,373.0	13	72.0	5,178.4
3	229.4	52,634.0	14	64.1	4,106.8
4	204.3	41,742.0	15	57.1	3,256.7
5	181.9	33,102.0	16	50.8	2,582.9
6	162.0	26,250.5	17	45.3	2,048.2
7	144.3	20,816.0	18	40.3	1,624.3

WIRING FOR LOW-POTENTIAL SYSTEMS.

32. Definition of Low-Potential System.—

LOW-POTENTIAL SYSTEMS.

550 Volts or Less.—

Any circuit attached to any machine or combination of machines that develops a difference of potential between any two wires of over 10 volts and

less than 550 volts shall be considered as a low-potential circuit and as coming under this class, unless an approved transforming device is used that cuts the difference of potential down to 10 volts or less. The primary circuit not to exceed a potential of 3,500 volts.

Before pressure is raised above 300 volts on any previously existing system of wiring, the whole must be strictly brought up to all of the requirements of the rules at date.

Until recently, low-potential systems were limited to 300 volts or under, but the limit has been raised to 550, but 550 volts cannot be applied to old systems unless the above rule is complied with. Low-potential systems are usually constant-potential systems also; that is, the potential or pressure between the terminals of the machine or at some definite points on the line is almost uniform. Only constant-potential systems will be considered under this heading.

A few general rules apply to the various kinds of work under these systems. They are as follows:

33. General Rules.—

Wires—

a. **Must be so arranged that under no circumstances shall there be a difference of potential of over 300 volts between any bare metal in any distributing switch, cut-out cabinet, or equivalent center of distribution.**

b. Must not be laid in plaster, cement, or similar finish and must never be fastened with staples.

c. Must not be fished for any great distance, and only in places where the inspector can satisfy himself that the rules have been complied with.

d. Twin wires must never be used, except in conduits or where flexible conductors are necessary.

e. Must be protected on side walls from mechanical injury. When crossing floor timbers in cellars or in rooms where they might be exposed to injury, wires must be attached by their insulating supports to the under side of a wooden strip not less than ½ inch in thickness and not less than 3 inches in width.

Suitable protection on side walls may be secured by a substantial boxing, retaining an air space of 1 inch around the conductor, closed at the top (the wires passing through bushed holes), and extending not less than 5 feet from the floor; or by an iron-armored or metal-sheathed insulating conduit sufficiently strong to withstand the strain it will be subjected to, and with the ends protected by the lining or by special insulating bushings, so as to thoroughly prevent the possibility of cutting the wire insulation; or by plain metal pipe, lined with tough conduit tubing, which must extend from the insulator next below the pipe to the one next above it.

If metal conduits or iron pipes are used with alternating currents, the two or more wires of a circuit *must* be placed in the same conduit to prevent troublesome induction and heating. They should also be so placed in direct-current wiring if there is any possibility of alternating currents ever being put on the system. In this case, the insulation of each wire must be reenforced by a tough conduit tubing extending from the insulator next below the pipe to the one next above it.

f. When run immediately under roofs or in proximity to water tanks or pipes will be considered as exposed to moisture.

34. The reason for the first part of (*b*) is that plaster and cement are likely to corrode the insulation on the wire and cause it finally to break. If the plaster is damp, leakage takes place, the wire is gradually dissolved by electrolysis, and finally it becomes so thin that it cannot carry its current without excessive heating and, perhaps, not without melting. While there are many places where wires embedded in plaster have been used for years without serious trouble, because of the dryness of the buildings where they are in use, trouble may develop at any time and the practice is always a dangerous one.

The second part of (*b*) is inserted as a direct prohibition against running electric-light wires as bell wires are usually put up. Staples not only do not insulate the wire, but are likely to cut into the insulating covering already on it. Rule (*c*) is to prevent the location of wires where it is impossible to know that they are properly supported and insulated.

SYSTEMS OF DISTRIBUTION FOR INTERIOR WIRING.

35. The voltages in common use on low-potential systems are: for continuous currents, 110 and 220; for alternating currents, 52 and 104. These are used on both two-wire and three-wire systems of wiring. Many lighting companies allow for various amounts of drop at different points on their lines and install lamps of different voltages, as, for instance, 108-volt lamps near the generator and 100-volt lamps at the extreme end of the line, with lamps of intermediate voltages at intermediate points. But the lamps used by any one building are usually all of the same voltage.

36. The Two-Wire System.—This is the simplest plan of wiring and the one in most general use. The sketch, Fig. 11, shows in diagram the essential features of this system. The diagram of connections is the same for all

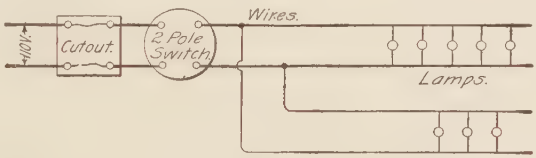


FIG. 11.

voltages and for alternating or continuous currents; but the fittings, such as lamps, sockets, cut-outs, and switches, and the sizes of wire used will be very different. The fittings and the proper size of wire to be used will be discussed later

37. The Edison Three-Wire System.—This system comes next in importance and extent of use. It also is used with various voltages and with continuous or alternating currents; but its chief field is on continuous-current circuits operated by two generators, with 110 volts between either outer wire and the middle or **neutral** wire and 220 volts between the outer wires. Fig. 12 shows the diagram of connections. This system is also sometimes installed with 220 volts between the neutral and outer wires and 440 volts on the outside wires.

Referring to the diagram, Fig. 12, observe the following: When the currents in the two outside wires are equal in amount, no current passes over the neutral wire; but when

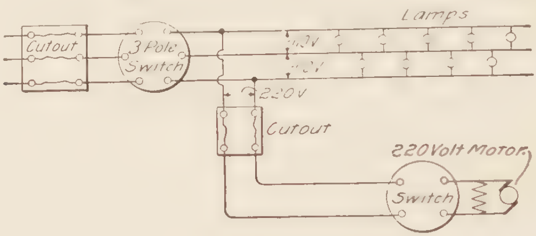


FIG. 12.

the currents are not equal, that is, when more lamps or motors are on one side of the neutral wire than on the other, the "difference current" flows on the middle wire.

38. The advantage of this system is that with lamps of any given voltage it is possible to save in the amount of wire required. In the outside lines of the lighting company is where the greatest saving is effected, because the neutral wire is there much smaller than the outer ones, and three wires are used instead of four, which would have to be run if the generators were operated independently. In interior wiring, the saving is not so great, because the neutral wire must be large enough to carry the current in case all the load is turned off one side of the circuit, as would be the case if the fuse on one side should blow and that on the other side did not, and because in small installations, where unbalancing is likely to occur, three-wire mains must be large to reduce this trouble to a minimum. This subject is explained later.

39. The three-wire system also has some disadvantages. Its most objectionable feature is that if any one line is opened, as by the blowing of a fuse on one line only, the system is unbalanced and a voltage different from that intended for the apparatus is thrown on the lines, unless the line loss is very small indeed. If it is the middle wire that opens,

the whole 220 volts may be thrown on 110-volt apparatus, if the system is much unbalanced. For this reason some Edison companies refuse to place cut-outs on the neutral wire; but the main switch should in all cases open all three lines. Another weakness of the three-wire system is the fact that there is more danger in 220 volts than in 110, and a shock received from a 220-volt circuit may be very severe. The wiring is somewhat more complicated, but owing to the saving in line materials, the Edison three-wire system has been introduced to a very great extent and still meets with much favor in new installations, besides extending the network of its wires from existing stations. Lately it has had a new competitor in the 220-volt two-wire system, which has grown in popularity with the perfecting of the 220-volt incandescent lamp.

40. It is the usual practice to run the three wires no farther within the building than to the centers of distribution, and from these centers to use the two-wire system, dividing the circuits as equally as possible on the two sides of the three-wire circuit, as shown in the sketch, Fig. 13. By this means, the branch lines are fused on both sides and amply protected against excessive currents, though not against high voltage. If the neutral wire within the building is protected by a fuse as large as that in either of the other main wires, the danger of that line opening is very small.

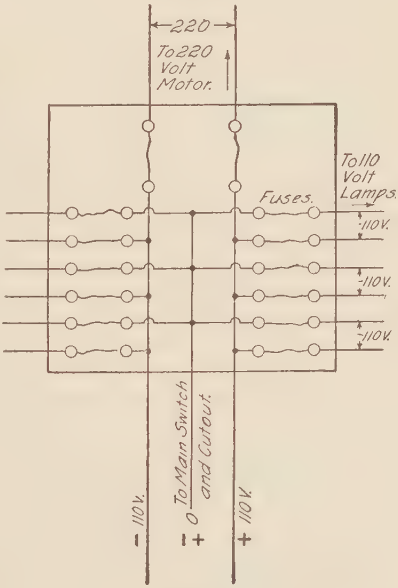


FIG. 13.

41. There is a method of running wires on the two-wire plan that is sometimes confused with the three-wire system; this is illustrated in Fig. 14. In this method the middle wire carries the whole current and each of the two outside wires carry what current is necessary for the lights on its side. This method effects no saving of copper; in fact, it

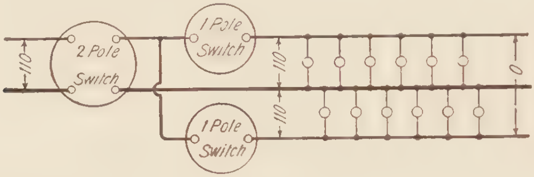


FIG. 14.

often requires more than the two-wire system would, because the three wires must generally be of the same size, as explained under the subject of cut-out protection. The object of the arrangement is solely to make it possible to turn off a number of the lights without running four wires. The Underwriters will not permit it with more than 660 watts on a side.

42. Systems like the three-wire system, but using more wires and, consequently, more generators, have been proposed; but none of them have come into commercial use to any extent in the United States, because they are easily unbalanced, because some of them give voltages too high for

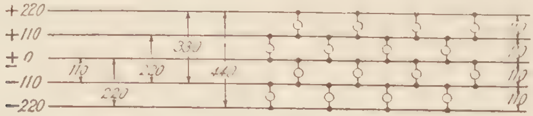


FIG. 15.

interior wiring (550 volts being the limit of low-tension working), and because they are too complicated. They are used to some extent on the continent of Europe. Fig. 15 is a diagram of such a system. No fittings are shown, but they must be numerous and complicated to make the arrangement approximately practicable.

MULTIPHASE SYSTEMS.

43. There are several systems for alternating currents only, known as **multiphase systems,** that require three or four wires. These, especially the *three-phase*, the *two-phase*, and the *monocyclic systems*, are very important, and diagrams, with brief descriptions of the essential connections, are therefore given. Fig. 16 represents lamps connected on a **three-phase circuit,** which requires three wires of equal size. The voltage is the same between any two wires, and it is desirable to divide the lights equally

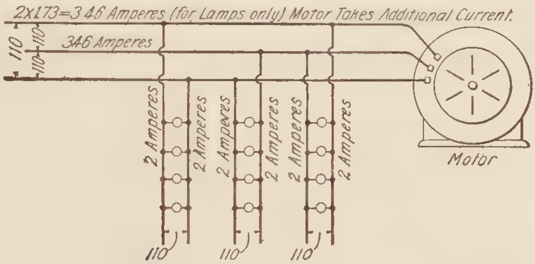


FIG. 16.

across the three pairs of lines, as shown. The sizes of wires for the branch lines (two-wire circuits) may be calculated as for any other two-wire circuit, as is explained later. The mains are of the same size as would be required if there were four wires, two on each of two separate two-wire circuits carrying the same total number of lamps. This system is easily unbalanced if the lamps are not equally divided. Cut-outs and switches (not shown on the sketch) must protect all three wires.

44. In a three-phase system, like that shown in Fig. 16, the current in the main wires is found by multiplying the current in the branch circuits by $\sqrt{3} = 1.73$. This assumes that the load on the three phases is balanced, as it should be in practice. This may be written in the form

$$C_m = C_b \times 1.73, \qquad (1.)$$

where C_m = current in each of the main wires;
C_b = current in branches.

In Fig. 16, the current in each branch is 2 amperes; hence, the current in the mains is $2 \times 1.73 = 3.46$ amperes. The method of determining the size of the mains will be taken up in connection with wiring calculations.

45. In the **two-phase system** the wires are sometimes arranged as in the Edison three-wire system, but the middle wire carries more current than either of the outer wires, instead of less. If the current in the outer wires is C and the current in the middle wire C_m, then

$$C_m = C \times 1.41. \qquad (2.)$$

The arrangement of circuits is as in Fig. 17. Lamps are connected between either outer wire and the middle wire and not between the outer wires. The system is easily

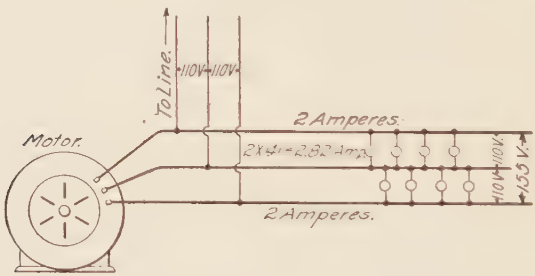


Fig. 17.

unbalanced. Three wires are run to the motors. Two-phase systems are generally installed as two separate two-wire systems, four wires being run to the motors and the

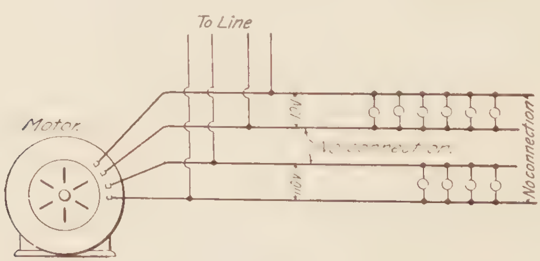


Fig. 18.

lights being divided equally on the two two-wire circuits. This gives better regulation (see Fig. 18). In this case, the

current in each of the four wires will be one-half that which would flow if all the lamps were operated on a regular two-wire system.

46. The **monocyclic system** is used only in transmission and in connection with motors. Wiring for lights on a monocyclic circuit is just the same as on any other two-wire circuit of the same voltage. The third wire is brought in only when a motor is installed. For its connections see Fig. 19.

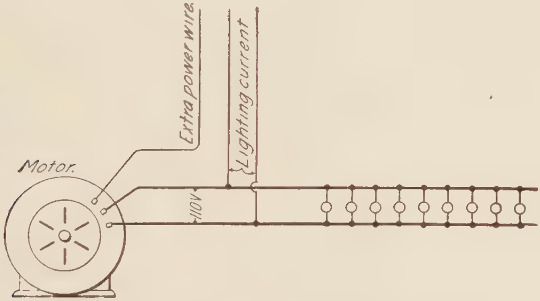


FIG. 19.

47. Generally speaking, multiphase circuits are used in transmission of power only, and not to distribute current to individual lamps. For final distribution, two-wire circuits should be used, and either connected with the three or four multiphase lines at the distribution center or supplied with single-phase current by the use of suitable transformers.

48. House wiring should consist of two distinct portions: the **distribution circuits**, which run from the lamps to a **center of distribution** and which should always be two-wire circuits, and the **mains**, which run from the outside lines to the distribution center and which must conform to the requirements of the particular system to be used. If mains must be installed before it is known what system is to supply current, it will be sufficient to run four separate wires of the size required if the lamps were to be divided equally between two separate two-wire systems. This will make it possible to connect to any system operating at the voltage for which the wiring calculations are made.

SWITCHES AND CUT-OUTS.

49. There are certain devices for the protection of constant-potential systems that are necessary no matter what voltage is used. Should anything happen to damage the wiring, it is necessary that the wires be disconnected from the source of supply of current with the least possible delay. The devices for this purpose that are operated by hand are called **switches.** Those that work automatically are called **automatic cut-outs.** These latter are of two kinds, **fuse blocks** and **circuit-breakers.**

Both a switch and an automatic cut-out must be placed at or near the place where wires enter a building. They must also be placed at various other points on the wiring.

50. The object of the cut-out is to protect the wires and the devices connected to them from damage due to the presence of too much current from any cause whatever. The ordinary cut-out consists of a porcelain base that carries suitable terminals for holding a piece of fusible wire, or **fuse,** which melts and opens the circuit whenever the current becomes excessive. Not only must the cut-out protect the lines when there is trouble, but it must be so placed that it can be reached to replace the fuse or reset the circuit-breaker when the trouble is remedied. It must also be arranged so that the blowing of a fuse or the opening of a circuit-breaker cannot do any damage.

51. Switches are designed to disconnect the lines from the source of electricity, not only when there is trouble, but when convenience requires, as in turning off lights, starting and stopping motors.

Circuit-breakers are not as commonly used in interior wiring work as are fusible cut-outs. They are automatic switches controlled by an electromagnet and are made in a number of different styles. Whenever the current exceeds that for which the circuit-breaker is adjusted, the electromagnet attracts its armature and releases the switch, thus opening the circuit.

The following rules regarding these devices must be followed in all cases:

Switches, Cut-Outs, Circuit-Breakers, Etc.—

a. Must, whenever called for, unless otherwise provided, be so arranged that the cut-outs will protect, and the opening of the switch or circuit-breaker will disconnect, all the wires; that is, in a two-wire system the two wires, and in a three-wire system the three wires, must be protected by the cut-out and disconnected by the operation of the switch or circuit-breaker.

b. Must not be placed in the immediate vicinity of easily ignitible stuff or where exposed to inflammable gases or dust or to flyings of combustible material.

NOTE.—In buildings used for starch and candy factories, woodworkers, grain elevators, flouring mills, or other purposes where fittings are exposed to dust and flyings of inflammable material, cut-outs and switches should be placed in an approved cabinet outside of the dust rooms, or if necessary to locate same in the dust room, cabinet must be dust-proof and arranged with a self-closing door.

c. Must, when exposed to dampness, either be enclosed in a waterproof box or mounted on porcelain knobs.

Automatic Cut-Outs (Fuses and Circuit-Breakers)

a. Must be placed on all service wires, either overhead or underground, as near as possible to the point where they enter the building and inside the walls, and arranged to cut off the entire current from the building.

Where the required switch is inside the building, the cut-out required by this section must be placed so as to protect it.

b. Must be placed at every point where a change is made in the size of wire [unless the cut-out in the larger wire will protect the smaller].

This (*b*) means unless the current carried by the larger wire is less than the smaller wire will safely carry, the fuse being proportioned to protect the smaller wire. This is frequently the case when line wires are connected to fixture wires, which

are small so that they will go between the shells of fixtures and the gas pipe within.

> *c.* Must be in plain sight or enclosed in an *approved* box and readily accessible. They must not be placed in the canopies or shells of fixtures.

This rule (*c*) precludes the use of the small cut-outs that it was customary at one time to place within the fixture canopies.

> *d.* Must be so placed that no set of incandescent lamps, whether grouped on one fixture or several fixtures or pendants, requiring more than 660 watts shall be dependent on one cut-out. Special permission may be given in writing by the Inspection Department having jurisdiction for departure from this rule in the case of large chandeliers, stage borders, and illuminated signs.

On 52- or 110-volt circuits this is equivalent to not more than twelve 16-candlepower lamps; on 220-volt circuits, not more than ten 16-candlepower lamps. It is best to stay well under this limit, say about six lamps to a cut-out, except in the special cases mentioned in the rule.

> *e.* Must be provided with fuses, the rated capacity of which does not exceed the allowable carrying capacity of the wire, and when circuit-breakers are used, they must not be set more than about 30 per cent. above the allowable carrying capacity of the wire, unless a fusible cut-out is also installed in the circuit.

This is very important. A fuse block not properly fused is of no use whatever. Irresponsible parties sometimes place fuses much too large to protect the wire and which will destroy the cut-out if they should ever blow, besides doing other damage. Sometimes, also, fuse blocks are found having copper wire where the fuses should be; of course, they are of no use with such connections.

52. Circuit-breakers may be set so as to work with greater accuracy than fuses; they respond quicker to sudden overloads, for fuses require a little time to get hot

enough to melt. For this reason, circuit-breakers may be set for higher currents than fuses. If they are not so set, they will give trouble by opening the circuit on momentary overloads that would not be sufficient to melt the fuses. Circuit-breakers are usually installed to protect machines, while fuses protect wires and cables of the smaller sizes. Very large fuses should be avoided and circuit-breakers used in their stead. The largest currents should be cut off indirectly, as by lowering the voltage and shutting down the generator. But such very large currents are only used in special low-voltage work, in electrochemical processes, and electric furnaces.

53. Rules Relating to Switches.—

Switches—

> *a.* Must be placed on all service wires, either overhead or underground, in a readily accessible place, as near as possible to the point where the wires enter the building, and arranged to cut off the entire current.
>
> *b.* Must always be placed in dry, accessible places and be grouped as far as possible. Knife switches must be so placed that gravity will tend to open rather than close the switch.
>
> *c.* Must not be single-pole when the circuits that they control supply devices that require over 660 watts of energy or when the difference of potential is over 300 volts.

This rule (*c*) is important, because it restricts the number of lamps so severely.

> *d.* Where flush switches are used, whether with conduit systems or not, the switches must be enclosed in boxes constructed of or lined with fire-resisting material. No push buttons for bells, gas-lighting circuits, or the like shall be placed in the same wall plate with switches controlling electric-light or power wiring.

This requires an approved box in addition to the porcelain enclosure of the switch.

e. Where possible, at all switch or fixture outlets, a $\frac{7}{8}$-inch block must be fastened between studs or floor timbers, flush with the back of lathing, to hold tubes and to support switches or fixtures. When this cannot be done, wooden base blocks not less than $\frac{3}{4}$ inch in thickness, securely screwed to the lathing, must be provided for switches and also for fixtures that are not attached to gas pipes or conduit tubing.

54. Construction of Cut-Outs, Circuit-Breakers, Etc. Equally important as the location of these devices is their proper construction. The following rules should be given careful study before any of these supplies are purchased.

Cut-Outs and Circuit-Breakers—

a. Must be supported on bases of non-combustible, non-absorptive, insulating material.

b. Cut-outs must be provided with covers, when not arranged in approved cabinets, so as to obviate any danger of the melted fuse metal coming in contact with any substance that might be ignited thereby.

c. Cut-outs must operate successfully, under the most severe conditions they are liable to meet with in practice, on short circuits with fuses rated at 50 per cent. above and with a voltage 25 per cent. above the current and voltage for which they are designed.

d. Circuit-breakers must operate successfully, under the most severe conditions they are liable to meet with in practice, on short circuits when set at 50 per cent. above the current and with a voltage 25 per cent. above that for which they are designed.

e. Must be plainly marked, where it will always be visible, with the name of the maker and the current and voltage for which the device is designed.

Fuses—

a. Must have contact surfaces or tips of harder metal having perfect electrical connection with the fusible part of the strip.

b. Must be stamped with about 80 per cent. of the maximum current they can carry indefinitely, thus allowing about 25 per cent. overload before fuse melts.

With naked, open fuses of ordinary shapes and not over 500 amperes capacity, the *maximum* current that will melt them in about 5 minutes may be safely taken as the melting point, as the fuse practically reaches its maximum temperature in this time. With larger fuses a longer time is necessary.

Enclosed fuses, where the fuse is often in contact with substances having good conductivity to heat and often of considerable volume, require a much longer time to reach a maximum temperature, on account of the surrounding material, which heats up slowly.

c. Fuse terminals must be stamped with the maker's name, initials, or some known trade mark.

55. The Underwriters' Rules relating to switches specify in detail the requirements that a switch must fulfil. Most of these requirements relate to mechanical details that concern the switch manufacturer more than the wireman. The style of switches used for interior wiring will be described later, and we will at this point simply call attention to a few rules relating to ordinary snap or push switches that are more directly connected with the installation of interior wiring.

Snap Switches.—

a. The current-carrying parts must be mounted on non-combustible, non-absorptive, insulating bases, such as slate or porcelain, and the holes for supporting screws shall be countersunk not less than $\frac{1}{8}$ inch; in no case must there be less than $\frac{3}{64}$ inch space between supporting screws and current-carrying parts.

Subbases that will separate the wires at least $\frac{1}{2}$ inch from the surface wired over should be furnished for all snap switches used in exposed knob or cleat work.

b. Covers made of conducting material, except face plates for flush switches, must be lined on their sides and top with insulating, tough, and tenacious material at least $\frac{1}{32}$ inch in thickness, firmly secured, so that it will not fall out with ordinary handling. Side lining should extend slightly beyond the lower edge of the cover.

c. The handle, button, or any exposed part must not be in electrical connection with the circuit.

d. Must "make" and "break" with a quick snap and not stop when motion has once been imparted to the handle.

Must operate successfully at 50 per cent. overload in amperes and 25 per cent. excess voltage under the most severe conditions they are liable to meet in practice.

When slowly turned "on" and "off" at the rate of about two or three times per minute, must "make" and "break" the circuit 6,000 times before failing, while carrying the rated current.

e. Must be plainly marked, where it may be readily seen after the device is installed, with the name or trade mark of the maker and the current or voltage for which the switch is designed.

On flush switches, these markings may be placed on the back of the face plate or on the subplate. On other designs, they must be placed on the *front* of the cap, cover, or plate.

Switches that indicate upon inspection whether the current be "on" or "off" are recommended.

Some of the common styles of switches and cut-outs will be described later when the methods of wiring are taken up.

OPEN WORK IN DRY PLACES.

56. Open work is generally used in factories, warehouses, mills, and other places where there is no objection to having the wires in plain sight, or in old buildings, where the expense of concealed work overbalances the objectionable appearance in the mind of the owner of the house or of the tenant. It is the cheapest kind of construction and very often the safest. We will study how to wire a building by means of simple examples.

SIMPLE EXAMPLE OF FACTORY WIRING.

57. Consider a factory, such as a long machine shop, where there is but one floor to be wired. It is proposed to wire this for 110-volt enclosed-arc lamps and incandescent

lamps on the so-called **tree system**; that is, with but one set of mains or feeder wires leaving the dynamo and with other lines branching from these mains to the points where lamps are required. Let Fig. 20 represent the outlines of such a factory, in which incandescent lamps are to be hung on lamp cord at the points marked × and enclosed-arc

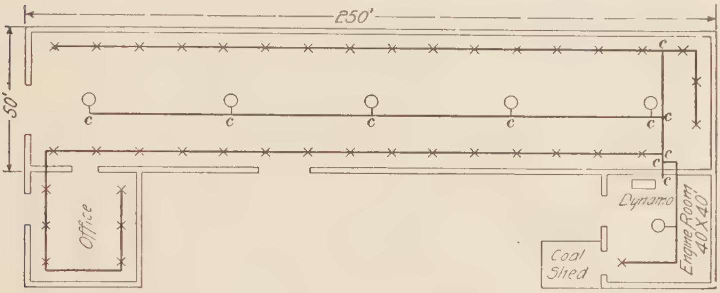


FIG. 20.

lamps are to be placed where the marks O are shown. Let us first consider what is the cheapest way in which this factory can be wired in order to satisfy the Underwriters; then we will see what modifications can be made to better the light, improve the system, and make it more convenient and economical in operation.

58. We will assume that each incandescent lamp is to be allowed 55 watts. Some good lamps take less power, but it is not safe to count on less. We also assume that each enclosed arc is to take 5 amperes while burning and 12 amperes to start on. There are 40 incandescent lamps and 6 arc lamps to be wired.

$$55 \text{ (watts)} \div 110 \text{ (volts)} = .5 \text{ (ampere per lamp)},$$
$$40 \times .5 = 20 \text{ (amperes for incandescent lamps)},$$
$$6 \times 5 = \underline{30} \text{ (amperes for arc lamps)},$$

Total amperes = 50,

which must be carried on the mains for a short distance at least.

Referring now to the table of Safe Carrying Capacities

(Table III), we see that the smallest wire that will carry 50 amperes with safety is No. 6 weather-proof.

59. Rules Relating to Wires for Open Work.—For open work in dry places we have the following rules regarding wires:

Wires—

a. Must have an *approved* rubber or "slow-burning" weather-proof insulation.

b. Must be rigidly supported on non-combustible, non-absorptive, insulators that will separate the wires from each other and from the surface wired over in accordance with the following table:

Voltage.	Distance From Surface. Inch.	Distance Between Wires. Inches.
0 to 300	½	2½
300 to 500	1	4

Rigid supporting requires under ordinary conditions, where wiring along flat surfaces, supports at least every 4½ feet. If the wires are liable to be disturbed, the distance between supports should be shortened. In buildings of mill construction, mains of No. 8 B. & S. wire or over, where not liable to be disturbed, may be separated about 4 inches and run from timber to timber, not breaking around, and may be supported at each timber only.

This rule will not be interpreted to forbid the placing of the neutral of a three-wire system in the center of a three-wire cleat, provided the outside wires are separated 2½ inches.

Slow-burning weather-proof wire is cheaper than rubber-covered wire and is suitable for this purpose. Various manufacturers make it. The following specifications will enable the wireman to determine whether wire offered him is up to the standard.

Slow-Burning Weather-Proof.—

a. The insulation shall consist of two coatings, one to be fireproof in character, the other to be weather-proof. The inner fireproof coating must comprise at least $\frac{6}{10}$ of the total thickness of the wall. The completed covering must be of a

thickness not less than that given in the following table for B. & S. gauge sizes:

Sizes of Wires Between Numbers.	Thickness of Insulation. Inch.
14–8	$\frac{3}{64}$
7–2	$\frac{1}{16}$
2–0000	$\frac{5}{64}$
0000–500,000	$\frac{3}{32}$
500,000–1,000,000	$\frac{7}{64}$
over 1,000,000	$\frac{1}{8}$

Measurements of insulating wall are to be made at the thinnest portion. Either the fireproof or the weather-proof coating may be on the outside.

b. The fireproof coating shall be layers of cotton or other thread, the outer one of which must be braided. All the interstices of these layers are to be filled with the fireproofing compound. This is to be material whose solid constituent is not susceptible to moisture, and which will not burn even when ground in an oxidizable oil, making a compound that, while proof against fire and moisture, at the same time has considerable elasticity and that when dry will suffer no change at a temperature of 250° F. and that will not burn at even higher temperature.

c. The weather-proof coating shall be a stout braid thoroughly saturated with a dense moisture-proof compound thoroughly slicked down, applied in such manner as to drive any atmospheric moisture from the cotton braiding, thereby securing a covering to a great degree waterproof and of high insulating power. This compound to retain its elasticity at 0° F. and not to drip at 160° F.

This wire is not as liable to burn as the old "weather-proof" nor as subject to softening under heat, but still is able to repel the ordinary amount of moisture found indoors It would not usually be used for outside work.

60. Determination of Sizes of Wire According to Current Capacity.—Observing the location of the lamps as shown in the diagram, we see that on each side of the building and down the center they are arranged in straight lines. It is evident, therefore, that it will be easier to run the wires along these lines and to fasten the rosettes (small porcelain fittings from which the lamps are suspended) directly to them, rather than put in short branch lines and run the principal wires on any other lines. We will, therefore, run the wires as shown in the sketch, where each line is supposed to represent a pair of wires put up on knobs or cleats.

61. We have now 18 incandescent lamps on one line, 21 on another, 5 arc lamps on a third, and 1 arc lamp and 1 incandescent lamp on a fourth. Referring again to the table of Carrying Capacities, we find that these lines will require wires of the following sizes: 21 incandescent lamps (10.5 amperes), No. 14 wire; 18 incandescent lamps (9 amperes), No. 14 wire; 5 arc lamps (25 amperes), No. 10 wire; 1 arc lamp and 1 incandescent lamp (5.5 amperes), No. 14 wire.

62. Location of Cut-Outs. — Since not more than 660 watts can be dependent on one cut-out, if we lay out the wiring as stated thus far, it will be necessary to have fuses in all the rosettes and also a separate cut-out at each arc lamp. Besides these cut-outs, there must be a cut-out at the point where each branch line joins the mains. The small wires running from the cut-outs to the arc lamps may be No. 14, which is large enough to carry the starting current of 12 amperes continually, if necessary. The locations of the cut-outs are indicated on the diagram by the letter *c*.

63. The wiring as now laid out, if put up properly, will comply with all the Underwriters' rules. The main switch and cut-out should be located near the dynamo in the engine room.

Such an arrangement as just described would not necessarily give satisfaction; it would merely be safe. But

before entering upon the matter of how to improve the plan of the wiring, we will consider some of the fittings and methods of work that should be used upon an installation of this kind.

FITTINGS USED FOR EXPOSED WIRING.

64. Open work must always be put up as though there were no insulation whatever on the

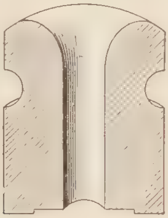


FIG. 21.

wires themselves. The wires must be supported on insulators so as not to come into contact with

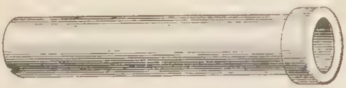


FIG. 22.

any woodwork, pipes, or any other thing except insulating supports.

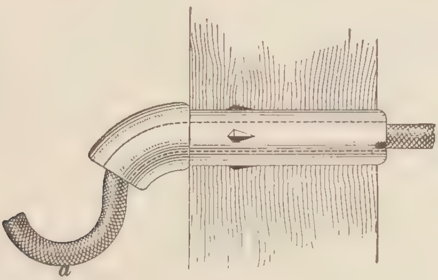


FIG. 23.

FIG. 24.

65. Fittings for Supporting Wire.—Some varieties of porcelain fittings suitable for this kind of work are shown in Figs. 21 to 30. These figures are typical examples only. Fittings of quite different designs may be used if they comply with the rules.

Fig. 21 shows an ordinary porcelain **knob** in section. These are made in various sizes, and the size used will depend somewhat on the size of wire to be accommodated. Fig. 22 shows the common 4-inch porcelain **tube** used where wires are run through joists. Fig. 23 is the style of tube used where wires are brought through window frames from the outside. The end is curved downwards to prevent water running in, and the **drip loop** *a* is formed to allow the water to drip off. A similar tube, only longer, is used for bringing wires in through brick or stone walls. Fig. 24 is a long, straight, porcelain tube used for passing through walls or floors. Note that the head *a* is some distance from the end, so that when the tube is used for carrying wires through floors, the exposed part of the wire will be above the floor.

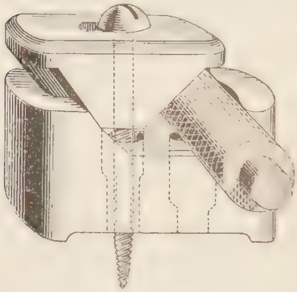


FIG. 25

Fig. 25 is a single-wire **cleat**, used more particularly for supporting fairly large wires. Fig. 26 shows a two-wire

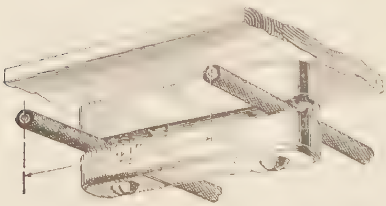


FIG. 26.

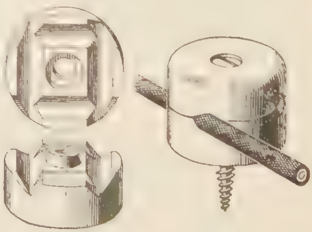


FIG. 27.

cleat designed to support the wires 2½ inches apart, in order to conform with the Underwriters' requirements. Many

different styles of cleats are made, but they are much the same in general construction. It is always best to put up cleats and knobs with screws, as a better job is done than when nails are used. Nails are, however, sometimes used,

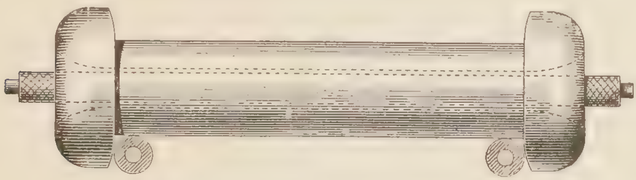


FIG. 28.

a leather washer being placed between the nail head and the porcelain, to prevent the latter from being cracked. Fig. 27 is a **knob cleat** used for supporting single wires where something neater than the ordinary knob is desired. It does away with the necessity of a tie-wire and is provided with four different sized grooves so that it will accommodate wires of various thicknesses. Fig. 28 shows a double-headed tube used when wires cross each other. Porcelain tubes should always be used where crossings of this kind occur. The tube, Fig. 22, is frequently used for this purpose; but if this is done, the end without a head should be taped to the wire to prevent the tube sliding along. Fig. 29 shows a fused **rosette** or ceiling cut-out. These rosettes are made in two parts, *a* and *b*. Part *a* is screwed to the

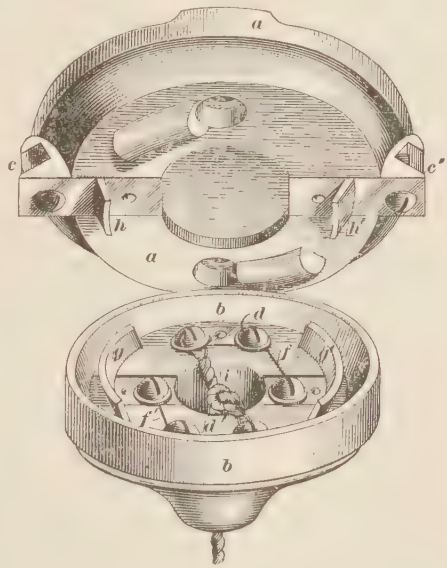


FIG. 29.

ceiling and the lamp is hung from the cap *b*. The lines are attached to the terminals *c*, *c'* and the lamp cord to *d*, *d'*; *f*, *f'* are the small fuses. When the cover *b* is attached to *a* by a twisting movement, terminals *g*, *g'* lock with *h*, *h'* and make the connection from the mains to the lamp. The cord should be knotted at *i* so that the pull will not come on the connections *d*, *d'*.

66. For such work as is now being considered, the principal porcelain articles required are the cleat, the rosette, and the cut-out. These are all made in several forms; some cleats are to be fastened with nails, others with screws. The selection of such fittings must be made with reference to the work in hand; for instance, cleats cannot be put up with nails on plastered walls, because the driving of nails will crack the plaster.

If the wires are placed high out of reach and the distance between the points of support is considerable, they should be separated a foot or more and fastened to knobs. Where passing through walls or partitions, the wires should be protected by porcelain bushings.

If a lamp is needed not more than 3 feet from the direct line of the wires, it can be hung where required by means of a **ceiling button,** Fig. 30; but lamp cord must not be used to run lamps in this way more than 2 or 3 feet from the rosette.

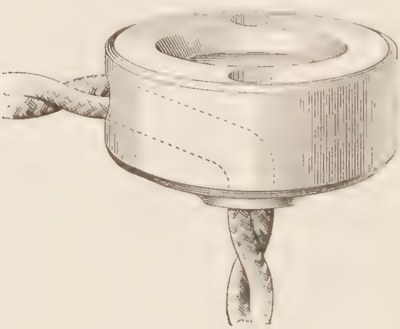


FIG. 30.

67. Flexible Lamp Cord.—In selecting lamp cord for this kind of work and in securing good sockets, too much care cannot be taken, for trouble occurs more frequently in lamp cord and sockets than in any other part of the wiring, if these articles are not of the highest grade. There is much temptation to use lamp cord for other purposes than those for which it is designed. The

rules regarding it are given here, and special attention is directed to them :

Flexible Cord—

a. Must have an *approved* insulation and covering.

b. Must not be used where the difference of potential between the two wires is over 300 volts.

c. Must not be used as a support for clusters.

d. Must not be used except for pendants, wiring of fixtures, and portable lamps or motors.

e. Must not be used in show windows.

f. Must be protected by insulating bushings where the cord enters the socket.

g. Must be so suspended that the entire weight of the socket and lamp will be borne by knots under the bushing in the socket, and above the point where the cord comes through the ceiling block or rosette, in order that the strain may be taken from the joints and binding screws.

68. As there is much inferior lamp cord on the market, the specifications for lamp cord are given here. Only brands that comply with these specifications should be used.

Flexible Cord—

a. Must be made of stranded copper conductors, each strand to be not larger than No. 26 or smaller than No. 30 B. & S. gauge, and each stranded conductor must be covered by an approved insulation and protected from mechanical injury by a tough, braided outer covering.

For pendant lamps:

In this class is to be included all flexible cord that, under usual conditions, hangs freely in air and that is not likely to be moved sufficiently to come in contact with surrounding objects.

b. Each stranded conductor must have a carrying capacity equivalent to not less than a No. 18 B. & S. gauge wire.

c. The covering of each stranded conductor must be made up as follows:

1. A tight, close wind of fine cotton.

2. The insulation proper, which shall be either waterproof or slow-burning.

3. An outer cover of silk or cotton.

The wind of cotton tends to prevent a broken strand puncturing the insulation and causing a short circuit. It also keeps the rubber from corroding the copper.

d. Waterproof insulation must be solid, at least $\frac{1}{32}$ inch thick, and must show an insulation resistance of 50 megohms (50 million ohms) per mile throughout two weeks' immersion in water at 70° F., and stand the tests prescribed for low-tension wires as far as they apply.

e. Slow-burning insulation must be at least $\frac{1}{32}$ inch in thickness and composed of substantial, elastic, slow-burning materials that will suffer no damage at a temperature of 250° F.

f. The outer protecting braiding should be so put on and sealed in place that when cut it will not fray out, and where cotton is used, it should be impregnated with a flame-proof paint that will not have an injurious effect on the insulation.

For portables:

In this class is included all cord used on portable lamps, small portable motors, etc.

g. Flexible cord for portable use must have waterproof insulation, as required in section *d* for pendant cord, and, in addition, must be provided with a reenforcing cover especially designed to withstand the abrasion it will be subject to in the uses to which it is to be put.

For portable heating apparatus:

h. Must be made up as follows:

1. A tight, close wind of fine cotton.

2. A thin layer of rubber about $\frac{1}{100}$ inch thick or other cementing material.

3. A layer of asbestos insulation at least $\frac{3}{64}$ inch thick.

4. A stout braid of cotton.

5. An outer reenforcing cover especially designed to withstand abrasion.

This cord is in no sense waterproof, the thin layer of rubber being specified in order that it may serve merely as a seal to help hold in place the fine cotton and asbestos, and it should be so put on as to accomplish this.

69. Lamp Bases.—The style of lamp socket used in a given job of wiring will depend on the kind of **bases** that are on the lamps. A large number of different styles of lamp bases have been brought out, but the number has gradually been cut down until the three types shown in Fig. 31 cover practically all the lamps in use in the United

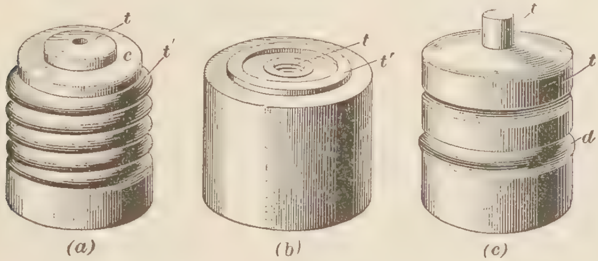


FIG. 31.

States; these are the Edison (*a*), the Thomson-Houston (*b*), and the Sawyer-Man, or Westinghouse (*c*). Of these three, the Edison base is the most popular and is gradually superseding the other two. In each case, the terminals of the socket are marked *t*, *t'*. When the lamp is placed in the socket, these make connection with corresponding terminals, thus connecting the circuit with the lamp.

70. Lamp Sockets and Receptacles.—A large variety of lamp sockets are manufactured, but they are all much the same in general design. Some of these are provided with keys for turning the light off or on; others are keyless—the light being controlled by a separate switch. The main thing to look out for in selecting sockets is to see that they are substantial, one of the most common sources of trouble on incandescent-lighting circuits being flimsy sockets that are continually getting out of order. Fig. 32 shows a typical key socket for an Edison base lamp. Sockets should be so constructed that the shell *a* will be insulated from the wires. Ordinary key sockets are suitable for work with incandescent lamps not exceeding 32 candlepower. The rubber or composition bushing shown in Fig. 33 must be used on all

sockets suspended from lamp cord in order to protect the cord where it passes through the shell.

Fig. 34 shows a waterproof, keyless socket for an Edison base. The terminals are surrounded by molded mica insulating material *a* and the wires *b*, *b* are attached directly to

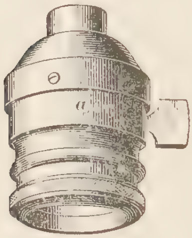


FIG. 32.

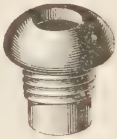
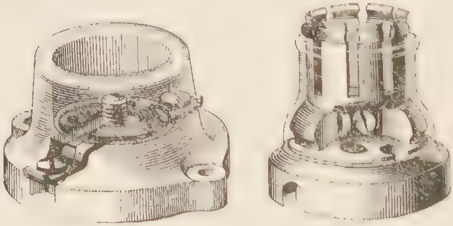


FIG. 33.

FIG. 34.

the mains. Waterproof sockets are also made of porcelain. Sockets of this type are required by the Underwriters whenever wiring is done in damp places, such as breweries, dye-houses, etc.

Fig. 35 (*a*) and (*b*) shows two styles of keyless receptacles. That shown in Fig. 35 (*a*) is almost entirely of porcelain and is designed for a lamp having a Thomson-Houston (T. H.) base. That shown in Fig. 35 (*b*) is provided with a porcelain base and a brass shell, the terminals being designed to take a Sawyer-Man, or Westinghouse, base.

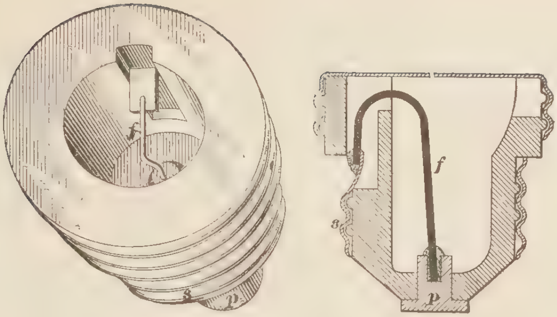


(*a*) (*b*)

FIG. 35.

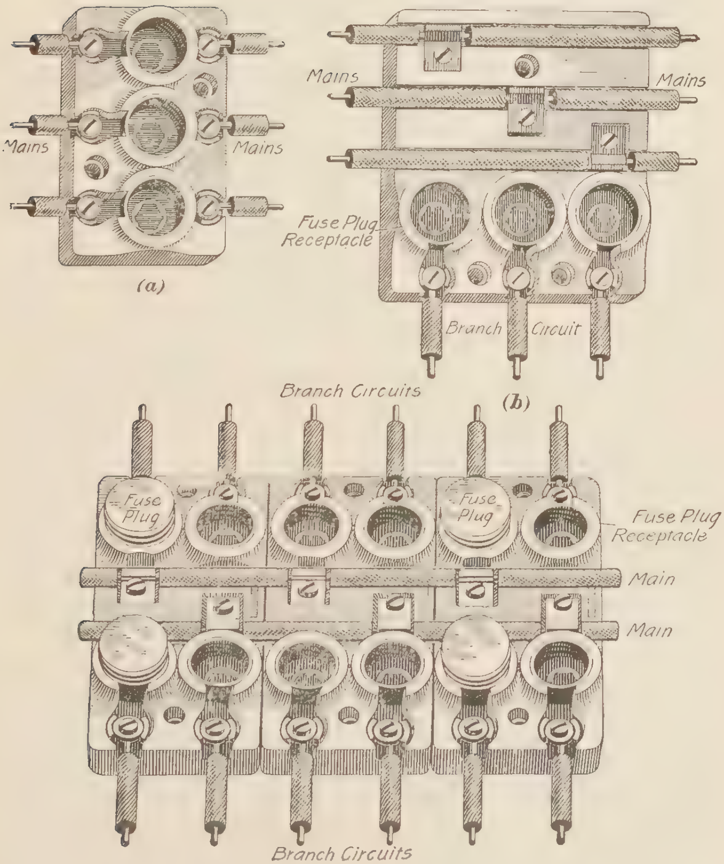
PORCELAIN FUSE BLOCKS.

71. Edison Plug Cut-Outs.—Among the suitable cut-outs for small currents on 52- or 110-volt work are the standard Edison **fuse-plug cut-outs.** These cut-outs are



(a) (b)

FIG. 36.



(c)

FIG. 37.

made for currents of from 5 to 30 amperes. The plug is provided with contacts like those of the Edison lamp base Cut-outs of this style are made for all combinations of two-wire and three-wire circuits, and several cut-outs can be connected together at a distribution center if desirable.

Fig. 36 (*a*) and (*b*) shows the construction of the Edison fuse plug. The fuse *f* is mounted in a porcelain or glass holder and attached to the screw terminal *s* and the contact *p*. These plugs screw into the receptacles on the fuse block, and whenever a fuse blows, a new plug is inserted.

Fig. 37 (*a*) shows a three-wire **main block** and Fig. 37 (*b*) a three-wire **branch block.** Fig. 37 (*c*) shows three two-wire **double branch blocks** grouped together to form a distributing center. The advantages of this type of fuse are that it is enclosed and that it gives good contact between the fuse and the fuse-block terminals. On the other hand, it is somewhat more expensive than the link fuse.

72. Link Fuses and Fuse Blocks.—Fig. 38 shows an ordinary link fuse. It consists of a fusible wire or strip *c* (generally made of a mixture of lead and bismuth) provided with copper terminals *a*, *b*. These terminals are necessary, because the fuse wire is soft and is almost sure to be cut if placed under the binding screws on the cut-out.

FIG. 38.

When link fuses are used, they must comply with the following specifications:

For Circuits of Not Over 125 Volts.—

Links on non-combustible bases enclosed in fireproof cabinets. Minimum break distance, 1¼ inches; minimum separation of terminals of opposite polarity, unless separated by ample partitions, 1¼ inches. *Fuses to be held free of contact with any portion of the base.*

For Circuits of Not Over 250 Volts.—

Links on non-combustible bases enclosed in fireproof cabinets. Minimum break distance, 2½ inches;

> minimum separations of terminals of opposite polarity, unless separated by ample partitions, $2\frac{1}{2}$ inches. *Fuses to be held free of contact with any portion of the base.*

For open work, where the fuse blocks are not enclosed in

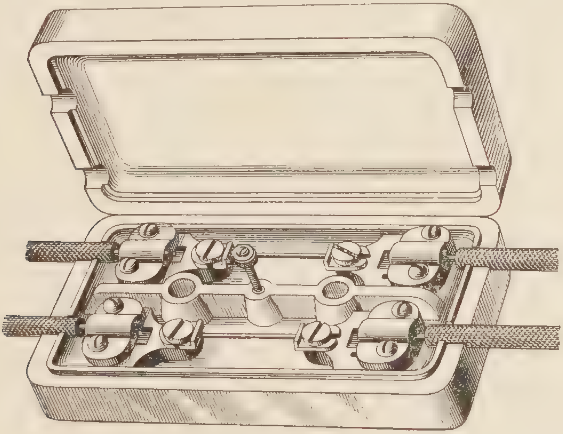


FIG. 39.

fireproof cabinets, they must be provided with suitable covers to prevent the melted metal of the fuse wire coming into contact with inflammable material. They should also be so located that no damage will result if the cover is left off.

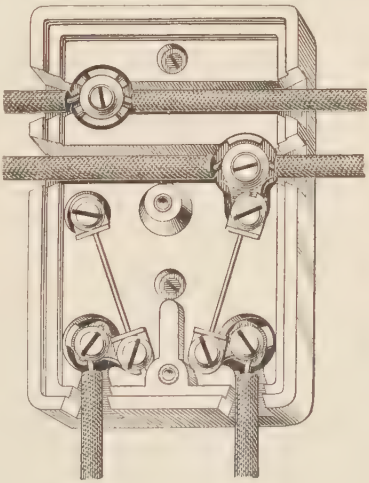


FIG. 40.

Figs. 39 and 40 show two styles of link fuse blocks, Fig. 39 being a main-line block with its cover and Fig. 40 a two-wire branch block with its cover omitted. Some manufacturers rate their wares as capable of carrying larger currents than should be allowed. Care

should be taken not to use such fittings except within their proper range.

73. Enclosed Fuses.—The use of link fuses is gradually giving way to that of enclosed fuses. The Edison plug is one type of enclosed fuse, but there are many other varieties in which the fuse is sealed in a tube or cartridge filled with material which does not conduct heat readily. The fuse is thus protected from injury and is more likely to melt at its rated capacity. One type of enclosed fuse block is shown in Fig. 44.

WIRING FOR A UNIFORM DROP.

74. In the method of wiring illustrated in Fig. 20, it will be noticed that the lamp on the extreme end of the line in the office is much farther away from the dynamo than the first lamp on that line. Owing to the resistance of the wire, the distant lamp will not burn as brilliantly as the nearer one; therefore, it is desirable to have a system of

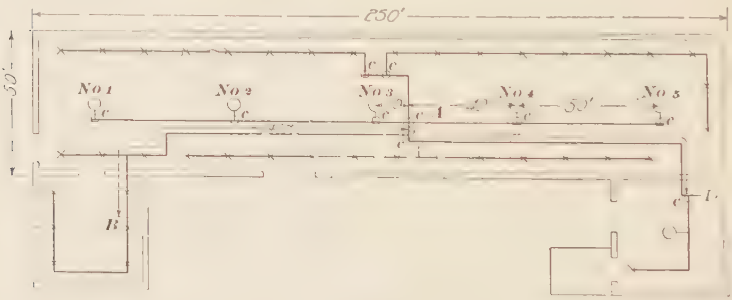


FIG. 41.

wiring on which the lamps will all glow with equal brightness. Also, it is not desirable in many cases to have a rosette with a fuse at each lamp, as this means many small fuses. Many very small fuses are not as reliable as a few larger ones and they cause more trouble. We will, therefore, plan to wire this establishment so as to avoid these two undesirable conditions. Fig 41 represents the factory so

wired. Where joints are made without changing the size of the wire, no cut-outs are required. In these wiring diagrams but one line is drawn to represent the two wires that must be installed.

In the wiring diagram shown in Fig. 41, there being less than 660 watts on any branch circuit, fuses may be omitted from the rosettes (or fuseless rosettes installed). Fuses of a proper size to protect the lamp cord must be placed in the cut-outs, that is, 6-ampere fuses if No. 16 cord is used. In such an installation, No. 18 lamp cord cannot be used without fused rosettes, unless not more than 6 lamps are placed on a branch circuit, because a 3-ampere fuse is required to protect No. 18 wire, and if placed in a cut-out, it will not allow current to pass for more than 6 110-volt lamps. The sizes of wires permitted by the insurance rules will be the same as in the first case studied.

75. We will now take up the subject of line calculations with reference to loss of power, or **drop** in potential. Table V gives the resistance of pure copper wire at 75° F. (24° C.), which is the temperature at which wiring calculations are usually made. The conductivity of commercial copper wire is from 98 to 99.5 per cent. of that of pure copper.

In ordinary interior wiring, the variations in resistance due to changes in temperature are usually disregarded, although they must be taken into account in the design of most kinds of electrical apparatus where they affect the regulation very much, as, for instance, in the field coils on a generator. The greatest variation in temperature at all likely to occur, and that will occur but rarely and only in open work, is about 100° F. This will correspond to a change in resistance of about 21 per cent.

The resistances of wires smaller than No. 18 are of no use in practical wiring, but are given for reference, as small wires are used in many pieces of mechanism, such as fan motors, resistance boxes, etc. with which wiremen have to deal, and also in bell and annunciator work.

TABLE V.

RESISTANCE OF PURE COPPER WIRE.

Number B. & S.	Resistance at 75° F.		
	Ohms Per 1,000 Feet.	Ohms Per Mile.	Feet Per Ohm.
0000	.04893	.25835	20,440.000
000	.06170	.32577	16,210.000
00	.07780	.41079	12,850.000
0	.09811	.51802	10,190.000
1	.12370	.65314	8,083.000
2	.15600	.82368	6,410.000
3	.19670	1.03860	5,084.000
4	.24800	1.30940	4,031.000
5	.31280	1.65160	3,197.000
6	.39440	2.08250	2,535.000
7	.49730	2.62580	2,011.000
8	.62710	3.31110	1,595.000
9	.79080	4.17530	1,265.000
10	.99720	5.26570	1,003.000
11	1.25700	6.63690	795.300
12	1.58600	8.37410	630.700
13	1.99900	10.55500	500.100
14	2.52100	13.31100	396.600
15	3.17900	16.78500	314.500
16	4.00900	21.16800	249.400
17	5.05500	26.69100	197.800
18	6.37400	33.65500	156.900
19	8.03800	42.44100	124.400
20	10.14000	53.53900	98.660
21	12.78000	67.47900	78.249
22	16.12000	85.11400	62.050
23	20.32000	107.29000	49.210
24	25.63000	135.53000	39.020
25	32.31000	170.59000	30.950
26	40.75000	215.16000	24.540
27	51.38000	271.29000	19.460
28	64.79000	242.09000	15.430
29	81.70000	431.37000	12.240
30	103.00000	543.84000	9.707
31	129.90000	685.87000	7.698
32	163.80000	864.87000	6.105
33	206.60000	1,090.80000	4.841
34	260.50000	1,375.50000	3.839
35	328.40000	1,734.00000	3.045
36	414.20000	2,187.00000	2.414
37	522.20000	2,757.30000	1.915
38	658.50000	3,476.80000	1.519
39	830.40000	4,384.50000	1.204
40	1,047.00000	5,528.20000	.955

76. The efficiency of a system of electric wiring depends on the amount of power that is consumed in heating the wires instead of being conveyed to the lamps or other transforming devices. This loss of power (in watts) is equal to the volts *drop* in the line multiplied by the *current* in *amperes*. Wiring specifications usually call for so many volts drop or not more than a certain percentage of drop on the line between the lamps and the center of distribution and between the center of distribution and the point where the wires enter the building or where the dynamo is located.

CALCULATION OF LINE LOSSES DUE TO RESISTANCE.

77. We will now calculate the drop on the wires in the factory shown in Fig. 41, using the smallest wires permitted by the Underwriters. The distance from the dynamo D to the point marked A, which is the average distance that the current travels on the No. 6 wire, is 150 feet (allowing for risers to a ceiling 15 feet high). As there must be two wires, the total length of wire is 300 feet.

The resistance of 1,000 feet of No. 6 wire (Table V) is .39440 ohm; therefore, the resistance of 300 feet of No. 6 wire is $.3 \times .39440 = .11832$ ohm. This line carries 50 amperes. By Ohm's law, the drop is given by the following relation:

Drop in line (volts) = current in line × resistance of line;

hence, $$\text{Drop} = 50 \times .118 = 5.9 \text{ volts.}$$

The line from A to B carries current for 9 lamps, or 4.5 amperes. Its distance is 140 feet and the resistance of the No. 14 wire is 2.521 ohms per 1,000 feet; hence

$$\text{Drop} = 4.5 \times \frac{2 \times 140}{1{,}000} \times 2.521 = 3.1765 \text{ volts}$$

drop on the branch line of No. 14 wire.

The total drop from D to B will then be $5.9 + 3.18 = 9.08$ volts. This is 8.3 per cent. of 110 volts, altogether too much for such a plant as we have been considering.

The reason why such a large loss must not be permitted, in addition to the simple matter of economy of power, is that such a large falling off in voltage will greatly reduce the brightness of the lamps and poor service will result. The cost of power alone, however, is usually a sufficient reason to prohibit such great losses in the wiring.

78. The plant we are considering requires 50 amperes at 110 volts, or 5,500 watts. This, if furnished by a lighting company, will cost between 10 cents and 20 cents a kilowatt-hour, at the rates ordinarily charged. That will be from \$.55 to \$1.10 an hour for light. 8.3 per cent. of this is 4.565 cents to 9.13 cents an hour. If the lights are used an average of 2 hours a day 300 days a year, this will amount to from \$27.39 to \$54.78 a year. If the loss were one-fourth as great, the saving in the cost of light in one year would more than pay for the additional cost of wire.

It is usual to specify a 2-per-cent. drop for such installations as this when the current is to be purchased at fairly high prices, and a 3-per-cent. to 5-per-cent. drop where the current is produced cheaply, as by a dynamo on the premises. Not more than a 5-per cent. drop should be permitted on short distances, even where very cheap work is desired. This would be accomplished in this case by using No. 4 wire for the feeders and No. 12 for the branch lines. The student may calculate the loss exactly by the use of Table V.

79. Drop in Arc-Light Wiring.—The loss on the arc lines using No. 10 wire from the point *A* is found as follows: The resistance of No. 10 wire is about 1 ohm per 1,000 feet.

$$\text{Drop from } A \text{ to lamp No. } 3 = 15\,(\text{amperes}) \times \frac{2 \times 10\,(\text{feet})}{1{,}000} = .3 \text{ volt;}$$

$$\text{Drop from lamp No. } 2 \text{ to lamp No. } 3 = 10 \times \frac{2 \times 50}{1{,}000} = 1 \text{ volt;}$$

$$\text{Drop from lamp No. } 1 \text{ to lamp No. } 2 = 5 \times \frac{2 \times 50}{1{,}000} = .5 \text{ volt;}$$

Drop from lamp No. *4* to lamp No. *5* = .5 volt;

$$\text{Drop from } A \text{ to lamp No. } 4 = 10 \times \frac{2 \times 40}{1{,}000} = .8.$$

Total drop at lamp No. *1* = .3 + 1 + .5 = 1.8 volts;
Total drop at lamp No. *2* = .3 + 1 = 1.3 volts;
Total drop at lamp No. *3* = .3 volt;
Total drop at lamp No. *4* = .8 volt;
Total drop at lamp No. *5* = .8 + .5 = 1.3 volts.

These slight variations can be permitted on the arc lamps without inconvenience.

80. Size of Wire for Arc Lights.—It should be noted that No. 10 wire is the smallest permitted on this line if the

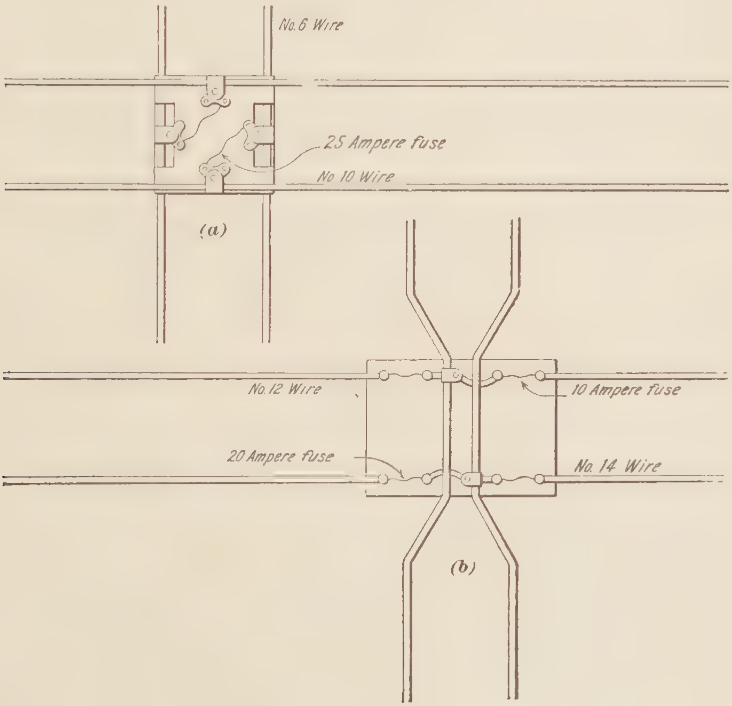


FIG. 42.

line is protected by but one cut-out. But if the line is divided into two parts, one for lamps Nos. *1*, *2*, and *3* and

one for lamps Nos. *4* and *5*, with separate cut-outs for each of these lines, smaller wires may be used, so far as the Underwriters' rules are concerned. Fig. 42 shows the sizes permitted (*a*) with a single branch block and (*b*) with a double branch block.

The wires that have their sizes designated by odd numbers from No. 7 up are not usually manufactured for line work and cannot be purchased except on special order. Therefore, work must be done without using Nos. 7, 9, 11, and 13. The resistances of these sizes, however, are given in the table, and these wires are extensively used in the manufacture of electrical machinery. In tables given later, the above sizes are not given, although in a number of cases they would come nearer the calculated size. In interior wiring, it does not, as a rule, pay to split hairs over the sizes of wire, and the nuisance of carrying a large number of sizes of wire in stock more than counterbalances any slight gain there might be in the copper used on a given job. For this reason, the above odd sizes are not generally used. Moreover, the tendency is always to add more lights to a system, and it is best to be liberal when installing the wire.

CALCULATION OF THE PROPER SIZE OF WIRE FOR A GIVEN LOSS.

81. Wiring for 110 Volts, 2-Per-Cent. Drop.—We will now calculate the sizes of wires required in the building wired according to Fig. 41 for a loss of 2 per cent. (2 per cent. of 110 = 2.2 volts).

This calculation will be made with a view to making the drop uniform along all the lines. That is, we will make the volts drop per foot of line equal as nearly as possible in feeders and branches. The proper value of volts drop per foot is found by allowing the desired drop to the farthest lamp in the system and distributing this drop uniformly along the lines to the generator, or center of distribution.

The average distance from the dynamo to the farthest lamps is $150 + 140 = 290$ feet. This requires 580 lineal feet of wire, or .580 thousand feet, there being two lines.

$$\frac{2.2 \text{ (volts)}}{.580} = 3.8 \text{ volts per } 1{,}000 \text{ ft.}$$

3.8 (volts) $\div$ 50 (amperes) $= .076$ ohm per 1,000 ft. for mains

The nearest wire to this is No. 00, with .078 ohm per 1,000 feet. Using this, the loss on the mains will be $.3 \times .078 \times 50 = 1.17$ volts, leaving $2.2 - 1.17 = 1.03$ volts to be lost in the distribution lines and $1.03 \div .28 = 3.68$ volts per 1,000 feet in the branch lines. The wire nearest to this is No. 9.

The student will see at once that in making a saving of about 7 per cent. (9.13 — 2.2 volts) in efficiency he has been obliged to use about five times as much copper, and that if the distances are long and the losses must be small, the cost of wire will prohibit the use of low voltages.

82. Wiring for 220 Volts, 3-Per-Cent. Drop.—As a further exercise in calculating the required sizes of wires in terms of resistances per 1,000 feet, let us ascertain the proper sizes of wire to equip the factory with 220-volt lamps, allowing 3 per cent. loss.

As 220-volt lamps are not as efficient as 110-volt lamps, we will allow 60 watts per 16-candlepower lamp and 3 amperes per enclosed-arc lamp. The four circuits for incandescent lamps carry approximately equal loads and are of about the same length, so that if we calculate the size of wire to use on one of them, we will have found the proper size for them all.

10 (lamps) $\times$ 60 (watts per lamp) $\div$ 220 (volts) $= 2.73$ amperes

$$\begin{aligned} 4 \times 2.73 &= 10.92 \text{ amperes for incandescent lamps.} \\ 5 \times 3.00 &= \underline{15.00} \text{ amperes for arc lamps.} \\ & 25.92 \text{ amperes total current.} \end{aligned}$$

3 per cent. of 220 volts is 6.6 volts.

$$\frac{6.6}{.580} = 11.38 \text{ volts lost per 1,000 feet;}$$

$$\frac{11.38}{25.9} = .44 \text{ ohm per 1,000 feet for the mains.}$$

The wire with resistance nearest this is No. 6, with .394 ohm per 1,000 feet. Using this size, we will have a loss on the mains of $.3 \times .394 \times 25.9 = 3.07$ volts, leaving 3.53 volts to be lost on branch lines.

The size of these branch lines will, therefore, be found as follows:

$\frac{3.53}{.28}$ = volts drop per 1,000 feet in branch lines and $\frac{3.53}{.28} \div 2.73$ = 4.62 ohms per 1,000 feet.

Table V gives 4.009 ohms per 1,000 feet for No. 16 wire, which is smaller than the Underwriters will permit. No. 14 must be used, even though it is larger than necessary as far as the drop is concerned. The loss will then be on the branch line $.28 \times 2.526 \times 2.73 = 1.93$ volts, leaving $6.60 - 1.93 = 4.67$ volts to be lost in the mains, instead of 3.07, as previously calculated.

$$\frac{4.67}{.3} \div 25.9 = .6 \text{ ohm per 1,000 feet in feeders.}$$

No. 8 wire has .627 ohm per 1,000 feet and is nearest the required size.

In 220-volt wiring, where the distances within the building are short, the wireman will usually find that the minimum sizes of wires specified by the Underwriters are large enough to carry the current with less than 2 per cent. loss. In small dwellings wired on the closet system of distribution with 220-volt circuits, it will not be necessary to pay any attention whatever to the drop on inside lines.

83. Center of Distribution.—In making calculations relating to wiring, the distance to be taken is the *average distance* through which the current supplied can be considered as flowing. For example, take a case like that

shown in Fig. 43, where a circuit is run from a distributing point A to a number of lamps B. For the first 100 feet no lamps are connected; we then have, say, 12 lamps spread out over 50 feet at the end. In calculating the drop on such a circuit, it is evident that the full length should not be taken, because the whole of the current does not flow through all the line. The current keeps decreasing as each lamp is passed. The center of distribution for the lamps will, therefore, be at C and the average length of wire through which the 6 amperes is carried is $2 \times 125 = 250$ feet. If the lights were

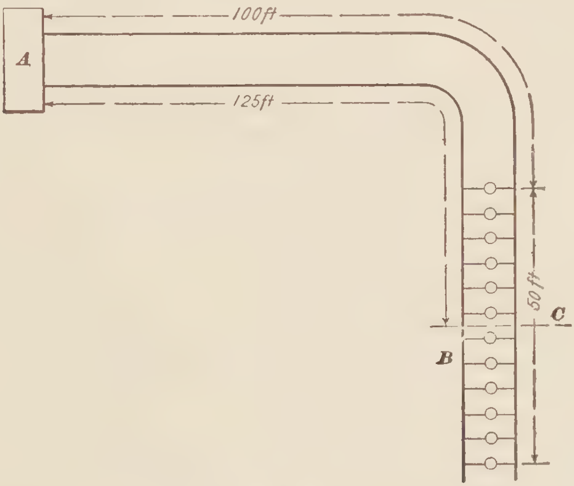


FIG. 43.

all bunched at the end of the line, the distance to the center of distribution would then be the same as the length of the line, and the length of wire through which the 6 amperes would flow would be $2 \times 150 = 300$ feet. If the lights were spaced uniformly throughout the whole length of the line, the average distance would then be $\frac{150}{2} = 75$ feet and the average length of wire used in making calculations for drop would be 150 feet. By laying out a plan of the wiring, the average distance over which the current is transmitted can usually be determined without much trouble and close enough for practical purposes.

EFFECT OF CONNECTING LOW-VOLTAGE CURRENT AND LAMPS TO WIRING CALCULATED FOR HIGH VOLTAGE.

84. The percentage of loss on any system of wiring is inversely proportional to the square of the voltage, if the watts transmitted are the same. That is, if we have 1 volt lost in transmitting 100 watts at 220 volts over a certain wire, we will have 4 volts lost in transmitting 100 watts at 110 volts over the same resistance, and 16 watts lost in transmitting at 55 volts. Let us see what would be the result if the factory wired for 220 volts, 3 per cent. loss, were connected to 52-volt supply wires and furnished with 52-volt lamps.

40 52-volt lamps taking 1 ampere each, 40 amperes.
5 alternating arc lamps.............. 50 amperes.
Total current.................. 90 amperes.

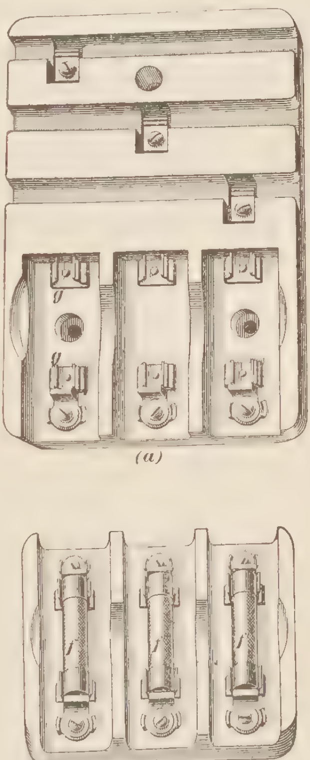
$$.627 \times .3 \times 90 = 16.93 \text{ volts lost in mains.}$$
$$2.53 \times .28 \times 10 = 7.08 \text{ volts lost in branches.}$$
$$\text{Total} = 24.01 \text{ volts lost in wiring.}$$

The actual volts drop will not be as great as this because the current will not be as great, owing to the resistance of the lines; for the lamps being supplied with considerably less than 52 volts will not take their full amount of current. These figures will be correct, however, if the lamps take 1 ampere each (as would 25-volt 8-candlepower lamps if they were substituted for the 52-volt 16-candlepower lamps). Here, then, is a loss of about 50 per cent. and a reduction of the power transmitted of 50 per cent. Leaving the 52-volt lamps in place, the actual voltage will be (since the resistance of the lines is about equal to one-half that of the lamps, or one-third the total resistance) about 35 volts. The main lines, moreover, will not carry a current of 60 amperes safely.

85. Selection of Fittings for 220-Volt Wiring.—In 220-volt wiring great care must be taken in the selection of fittings. Cut-outs, sockets, and switches designed for 110-volt working and not improved during recent years so

as to comply with the severer requirements of the present day must not be used on higher voltages. Keyless sockets should be used for 220-volt work and the lamps controlled by switches; no rosettes with fuses should be installed, fuses being placed in approved cut-outs, one of which should be provided for each ten lamps or less. If proper precautions are taken to procure good cut-outs, sockets, and switches, there is no especial difficulty to be encountered in 220-volt work, though the lamps are not as efficient as can be procured for lower voltages.

Fig. 44 (*a*) and (*b*) shows two cut-outs designed especially for 220-volt work. The construction is such as to secure higher insulation and less liability to arcing than with the ordinary 110-volt fittings. Fig. 44 (*a*) is a three-wire branch block shown without the fuses in place. Fig. 44 (*b*) is a three-wire main block with the fuses *f* in their proper position. These fuses are of the enclosed type; i. e., the fuse is enclosed in an insulating holder that, in this case, is held by clips *g*, *g*, (*a*).



(*a*)

(*b*)

FIG. 44.

Enclosed fuses have of late years become quite common. The idea is to prevent the fuse arcing when it blows and also to protect it. It is claimed that enclosed fuses are more reliable than open ones, because they may be depended on to blow more nearly at their rated current. Open fuses often come in contact with the cold porcelain base, and this has a marked influence on their fusing point. Drafts of air may also influence the fusing

point considerably. Enclosed fuses are now very generally used for 110-, 220-, and 500-volt work.

86. Size of Wire for Three-Wire System.—If it is desired to wire the shop which we have been considering for 110-volt lamps on the Edison three-wire system, the sizes of the main wires required will be the same as for the 220-volt two-wire system, and a third, or neutral, wire must be installed. This is usually placed between the other two, and if the wires are put upon cleats, three-wire cleats may be used. The neutral wire must not be smaller than will be required for the safe carrying capacity for the current of all the lamps on one side of the circuit. In this case, that current is 25 amperes and the wire must not be smaller than No. 10. It should be larger, to prevent unbalancing when lamps are turned off.

87. Unbalancing of Three-Wire System.—The unbalancing of a three-wire system with the three wires of equal size is illustrated in Fig. 45 (a) and (b). When the system is balanced as in (a), we have 3 amperes in the outside wires

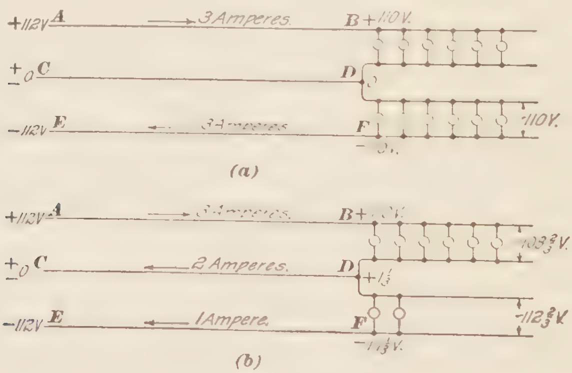


FIG. 45.

and no current in the neutral. We will take the pressure between A and C or C and E as 112 volts, and between B and D or D and F as 110 volts. There is, therefore, a drop of 2 volts in A B and also a drop of 2 volts in E F. The

resistance of $A\ B$, $C\ D$, and $E\ F$ must, therefore, be $\frac{2}{3}$ ohm, in order to give a drop of 2 volts with a current of 3 amperes. If the load becomes unbalanced, as in (*b*), there will be a current of 3 amperes in $A\ B$, as before, 2 amperes in $C\ D$, and 1 ampere in $E\ F$. The drop in $A\ B$ will be $\frac{2}{3} \times 3 = 2$ volts; in $C\ D$, $\frac{2}{3} \times 2 = 1\frac{1}{3}$ volts; in $E\ F$, $\frac{2}{3} \times 1 = \frac{2}{3}$ volt. The total drop in the two outside wires will now be $2 + \frac{2}{3} = 2\frac{2}{3}$ volts, and hence the pressure between the outside wires at the end of the line must be $224 - 2\frac{2}{3} = 221\frac{1}{3}$ volts. Taking the upper side of the circuit, we have 3 amperes flowing out through $A\ B$ and 2 amperes flowing back through $C\ D$; the drop on this side must, therefore, be $2 + 1\frac{1}{3} = 3\frac{1}{3}$ volts and the pressure between B and D must be $112 - 3\frac{1}{3} = 108\frac{2}{3}$ volts. The pressure between B and F is $221\frac{1}{3}$ volts; hence, the pressure between D and F must be $221\frac{1}{3} - 108\frac{2}{3} = 112\frac{2}{3}$. The result of the uneven load is, therefore, that the voltage rises in the lightly loaded side and falls on the side having a heavy load. If the neutral wire were smaller, this unbalancing would be greater.

The branch lines of a three-wire system must be calculated for the proper current and drop on 110 volts as two-wire circuits, because these branches are simple two-wire circuits.

INTERIOR WIRING.

(PART 2.)

UNIFORM DROP IN FEEDER LINES.

1. In installations where there are many sets of feeder lines running to various departments, it is usual to allow a certain loss in the feeders and a certain other loss in the distribution wires. The loss in all feeders is made the same, and the dynamo is operated at a higher voltage than the lamps will stand, with the intention of losing a definite amount before the lamps are reached. It is important that the voltage at the lamps should never exceed that for which they are intended.

2. Fig. 1 represents a factory, such as a wagon works or furniture factory. Only the outlines of the buildings are indicated. The dynamo and switchboard are located at *D* in the engine room. The various centers of distribution are to be at or near the centers of the various floors. A separate pair of mains is to be run to each distribution center. Where elevator shafts are convenient, they are used to run risers to the upper floors. In the case illustrated there are fourteen pairs of feeder wires, each pair being represented by one line in the figure.

A 115-volt dynamo and 110-volt lamps are to be used. A loss of 2 volts is to be allowed in the distribution wires and

For notice of copyright, see page immediately following the title page.

a loss of 3 volts in the feeders, irrespective of their length. The figure shows the plan of the feeders on one floor only; the small round dots indicate risers.

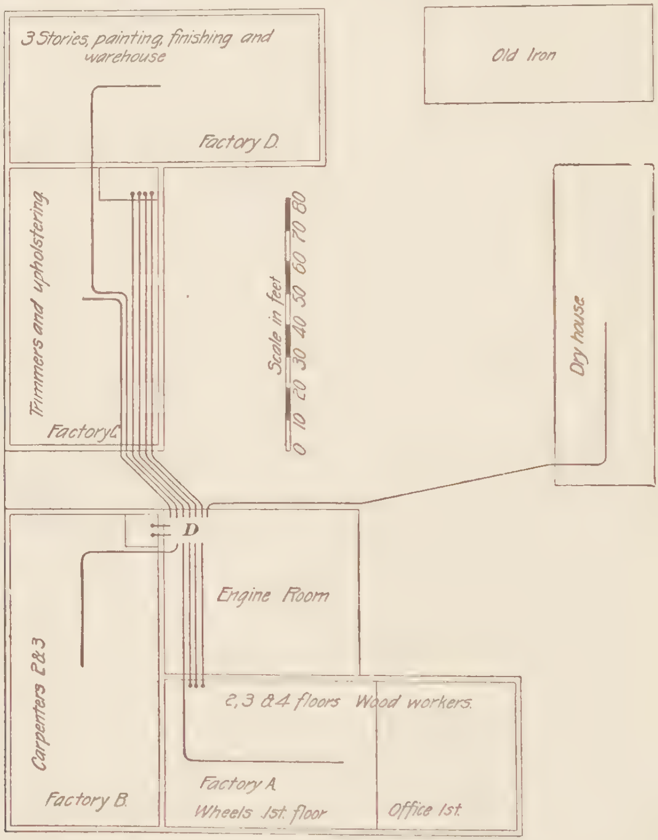


FIG. 1.

We will calculate the feeders on one floor only.

	Lamps.	*Amperes.*	*Distance.*	*Length of Wire.*
Shop *A*,	50	25	130 ft.	260 ft.
Shop *B*,	40	20	75 ft.	150 ft.
Shop *C*,	40	20	85 ft.	170 ft.
Shop *D*,	40	20	175 ft.	350 ft.

The resistance per 1,000 feet of these feeders required to give a drop of 3 volts and the nearest sizes of wires obtainable, are calculated as follows:

Shop A, $\frac{3}{25 \times .26} = .461$, No. 6 has .395 ohm per 1,000 feet.

Shop B, $\frac{3}{20 \times .15} = 1.000$, No. 10 has .999 ohm per 1,000 feet.

Shop C, $\frac{3}{20 \times .17} = .882$, No. 10 has .999 ohm per 1,000 feet.

Shop D, $\frac{3}{20 \times .35} = .429$, No. 6 has .395 ohm per 1,000 feet.

3. This method of calculating required sizes of wires can be applied to any kind of wiring for any practical purpose; but to avoid the necessity of figuring out each case, wiring tables have been prepared by which the proper size can be determined without calculation.

CALCULATION OF WIRE SIZES IN TERMS OF RESISTANCE PER 1,000 FEET.

4. Calculations based on resistance per 1,000 feet, such as have been made in previous examples, may be put in the shape of a formula as follows:

$$r_m = \frac{e \times 1{,}000}{2 \times D \times C}, \qquad \textbf{(1.)}$$

in which r_m is the resistance of 1,000 feet of the wire to be used, e the drop in volts, D the distance measured in feet, and C the current measured in amperes.

For example, to carry 10 amperes 600 feet ($600 \times 2 = 1{,}200$ feet of wire) with 3 volts drop, the resistance per 1,000 feet will be:

$$r_m = \frac{3 \times 1{,}000}{2 \times 600 \times 10} = .250 \text{ ohm per 1,000 feet.}$$

No. 4 wire has about this resistance, as may be seen by consulting a wire table

TABLE I.

Amperes.	Distances in Feet for Loss of 1 Volt.																
	20	25	30	35	40	45	50	60	70	80	90	100	120	140	160	180	200
1														14	14	14	14
1.5												14	14	12	12	12	12
2									14	14	14	14	12	12	12	10	10
3							14	14	12	12	12	12	10	10	10	8	8
4						14	14	12	12	12	10	10	10	8	8	8	8
5				14	14	12	12	12	10	10	10	10	8	8	8	6	6
6			14	12	12	12	12	10	10	10	8	8	8	6	6	6	6
7		14	12	12	12	12	10	10	10	8	8	8	6	6	6	6	5
8		14	12	12	10	10	10	10	8	8	8	8	6	6	6	5	5
9	14	12	12	12	10	10	10	8	8	8	8	6	6	6	5	4	4
10	14	12	12	10	10	10	10	8	8	8	6	6	6	5	5	4	4
12	12	12	10	10	10	8	8	8	6	6	6	6	5	4	4	3	3
14	12	10	10	10	8	8	8	6	6	6	6	5	4	4	3	3	2
16	12	10	10	8	8	8	8	6	6	5	5	5	4	3	3	2	2
18	10	10	8	8	8	8	6	6	6	5	5	4	3	3	2		
20	10	10	8	8	8	6	6	6	5	5	4	4	3	2	2		
25	10	8	8	6	6	6	6	5	4	4	3	3	2				
30	8	8	6	6	6	5	5	4	3	3	2	2					
35	8	6	6	6	5	5	4	3	3	2	2						
40	8	6	6	5	5	4	4	3	2	2							
45	6	6	5	5	4	4	3	2	2								
50	6	6	5	4	4	3	3	2									
55	6	5	4	4	3	3	2	2									
60	6	5	4	3	3	2	2										
65	6	5	4	3	3	2	2										
70	5	4	3	3	2	2											
75	5	4	3	2	2												
80	5	4	3	2	2												
90	4	3	2	2													
100	4	3	2														

Size Wire in B. & S. Gauge, Soft Copper.

5. Wiring Table Giving Distances for Drop of 1 Volt. In Table I, distances in feet are given in the top horizontal line. Beneath these distances are columns containing numbers that designate the proper size of wire to use to obtain a drop of 1 volt when the wire carries the current given in the corresponding line in the left-hand column.

If it is desired, for example, to find the size of wire necessary to get a loss of not more than 1 volt with 20 amperes, and a distance of 140 feet (i. e., two wires, 140 feet long, side by side), we look under 140 and to the right of 20 and find the figure 2. No. 2 wire will be required. If it is desired to find the wire required for a loss of 2 volts with 20 amperes and a distance of 140 feet, we may divide the distance by the loss in volts and use the table as before; i. e., under 70 and to the right of 20 is found 5. No. 5 is the proper wire. Or, we may use the distance given and divide the current by the number of volts; i. e., under 140 and to the right of 10 is found 5. The table is sufficiently accurate for all practical purposes. Where very great exactness is desired, it is better to calculate the lines. For the smaller sizes in this table, the nearest even sizes of wire are given because the odd sizes are not ordinarily used.

CALCULATION OF WIRES IN TERMS OF CIRCULAR MILS.

6. In the table of Safe Carrying Capacities (Part 1), the wires are listed both by number (B. & S. gauge) and by **circular mils.** Cables having no B. & S. gauge number are listed by circular mils only. Large cables of any desired cross-section in circular mils are made to order by all the leading manufacturers of insulated wires.

It is often more convenient to calculate the size of wires or cables in terms of circular mils than in terms of resistance per 1,000 feet; and calculations in terms of circular mils are applicable to wires or cables of any size or shape. A **mil** is another name for $\frac{1}{1000}$ inch.

A round wire 1 mil in diameter has a cross-section of

1 circular mil. A copper wire 1 mil ($\frac{1}{1000}$ inch) in diameter and 1 foot long (1 **mil-foot**) has a resistance of 10.8 ohms; or, 1 *mil-foot of pure copper has 10.8 ohms resistance at 75° F.*

A wire 2 mils in diameter has a section of 4 circular mils (abbreviated 4 C. M.); 3 mils in diameter, 9 circular mils; 4 mils, 16 circular mils; 5 mils, 25 circular mils; x mils, x^2 circular mils. *The circular mils cross-section of any round wire is equal to the square of its diameter in mils.* The circular mils of any conductor of other shape are equal to its area in *square mils* multiplied by 1.273 or divided by .7854. For instance, the circular mils of 0000 wire (diam. = 460 mils) $= 460^2 = 211,600$ circular mils, while a bar of copper $\frac{1}{4}$ inch by $\frac{1}{2}$ inch (250 mils by 500 mils) has a section of $250 \times 500 = 125,000$ square mils or $250 \times 500 \times 1.273 = 159,125$ circular mils.

7. If the length in feet of a wire is known and also its area in circular mils, the resistance may at once be determined by the formula

$$R = \frac{L \times 10.8}{\text{cir. mils}}. \qquad (2.)$$

In this formula, L must be the total length of wire in *feet*.

Also, since the drop e in a circuit is equal to the current C $\times$ resistance R, we have

$$\text{Drop } e = \frac{C \times L \times 10.8}{\text{cir. mils}}; \qquad (3.)$$

or if the drop is given and we are required to find the size of wire to give this drop, we may put formula **3** in the form

$$\text{Cir. mils} = \frac{C \times L \times 10.8}{e}. \qquad (4.)$$

In these formulas L is the total length of the circuit, i. e., the distance to the lamps and back again. If the distance to the lamps, one way, is called D, we may put formula **4** in the form

$$\text{Cir. mils} = \frac{21.6 \times C \times D}{e}. \qquad (5.)$$

8. This last formula will generally be found as useful as any that can be given for interior-wiring calculations. It will be well to commit it to memory, because one does not always have a wiring table at hand when calculations are to be made and, besides, calculations have often to be made that are beyond the range of the tables. It can be applied to any two-wire system or to the three-wire system, as illustrated by the following examples:

EXAMPLE 1.—By means of formula **5**, calculate the size of wire necessary to supply 80 16 c. p. lamps situated at a distance of 200 feet from the center of distribution. The allowable drop is to be 3 volts.

SOLUTION.—We have $D = 200$ and $e = 3$. Each 16-candlepower lamp will take about $\frac{1}{2}$ ampere; hence, $C = 40$.

$$\text{Cir. mils} = \frac{21.6 \times 200 \times 40}{3} = 57{,}600,$$

or between No. 2 and No. 3 B. & S. No. 2 wire would likely be used.

EXAMPLE 2.—Calculate the size of wire necessary to supply 100 lamps on a 110–220-volt three-wire system. The distance from the center of distribution to the lamps is 250 feet and the drop on each side of the system is not to exceed 3 volts. The lights are supposed to be balanced, 50 lamps on each side.

SOLUTION.—The simplest method of solving this problem is to treat it as if it were a two-wire system and use formula **5**. Each pair of lamps will take $\frac{1}{2}$ ampere; hence, the current in the outside wires, when all the lamps are burning, will be $\frac{100}{4} = 25$ amperes instead of $\frac{100}{2} = 50$ amperes, as it would have been if a two-wire system were used. The allowable drop on each side of the circuit is 3 volts; hence, the total drop in the outside wires will be 6 volts. We have, then,

$$\text{Cir. mils} = \frac{21.6 \times 25 \times 250}{6} = 22{,}500.$$

A No. 6 wire will be large enough and also would most likely be installed for the neutral.

The same method may be used for a 220–440-volt three-wire system, except that in estimating the current, allow about .3 ampere for each *pair* of lamps instead of .5 ampere, as in the previous case.

9. Estimation of Current Required by Lamps.—As previously mentioned, it is customary in estimating the current taken by lamps to allow about $\frac{1}{2}$ ampere for each

110-volt 16-candlepower lamp, and others according to the values given. The most accurate way, however, is to figure the current from the total watts supplied and the known voltage. For a two-wire system the current is as follows:

$$\text{Current} = \frac{\text{number of lamps} \times \text{watts per lamp}}{\text{voltage at lamps}}. \qquad \textbf{(6.)}$$

For a balanced three-wire system

$$\text{Current} = \frac{\text{number of lamps} \times \text{watts per lamp}}{\text{voltage between outside wires at lamps}}. \qquad \textbf{(7.)}$$

These formulas are general and apply to lamps of any efficiency.

CALCULATIONS FOR ALTERNATING CURRENT.

10. For ordinary two- or three-wire work with alternating current, calculations may be made in the same way as for direct current. When wiring is done in conduit, the two wires should be run in the same conduit, otherwise inductive effects will greatly reduce the voltage at the lamps. With ordinary open wiring, the induced counter E. M. F. is not usually large enough to produce any noticeable effects, especially when the load consists wholly of lamps.

11. Calculation of Lines for Three-Phase Lighting Mains.—If lights only are operated on a balanced three-phase three-wire system, the following formula may be used to determine the cross-section of the lines:

$$\text{Circular mils} = \frac{10.8 \times W \times D}{E \times e}, \qquad \textbf{(8.)}$$

where W = total number of watts supplied;
D = distance in feet to distributing center;
E = voltage at lamps;
e = drop in volts.

EXAMPLE.—Three hundred 16-candlepower 55-watt lamps are to be operated on the three-phase system at a distance of 100 feet from the source of supply. The E. M. F. between any two lines at the lamps is

to be 110 volts, and the drop in the line must not exceed 3 volts; find the size of wire required.

SOLUTION.— $W = 300 \times 55$, $E = 110$, $e = 3$, $D = 100$;

hence, $$\text{Circular mils} = \frac{10.8 \times 300 \times 55 \times 100}{110 \times 3} = 54{,}000,$$

or about No. 3 B. & S. wire. Ans.

In this example the lights will be divided equally between the three phases, i. e., 100 lights on each phase. Formula **8** may also be used for a four-wire two-phase system, but in this case four wires are needed as against three wires in the three-phase system.

The current in each line of the balanced three-phase system will be

$$C = \frac{W}{E \times 1.73}, \qquad \textbf{(9.)}$$

where W is the total number of watts supplied; i. e., three times the watts on one phase.

For a four-wire two-phase system, the current in each wire will be

$$C = \tfrac{1}{2} \frac{W}{E}, \qquad \textbf{(10.)}$$

because this is practically equivalent to two ordinary single-phase systems, each carrying half the load.

OTHER FORMS OF WIRING TABLES.

12. Before we leave the subject of wire calculations, the attention of the student is called to the fact that there are other methods of arranging wiring tables than that given in Table I, for it is easy to produce several arrangements of the same matter. The table that one is most accustomed to use seems the simplest. Tables calculated for incandescent lamps, instead of for amperes, are useless for general work and should not be used for calculating wiring for lamps, unless it is known that the efficiency of the lamps on which the table is based is the same as that of the lamps to be used.

TABLE II.

DISTANCE IN FEET PRODUCING A DROP OF 1 VOLT FOR GIVEN CURRENTS AND GIVEN SIZES OF WIRE.

Size of Wire, B. & S. Gauge. Amperes.	1	2	3	4	5	6	7	8	9	10	12	15	18	20	25	30	35	40	45	55	65	75	85	95	100
18	75.2	37.6	25.1	18.8	15.0																				
16	120.0	60.0	40.0	30.0	24.0	20.0																			
14	190.0	95.0	63.3	47.5	38.0	31.7	27.1	23.8	21.1	19.0	15.8	12.7													
12	302.0	151.0	101.0	75.5	60.4	50.3	43.1	37.7	33.6	30.2	25.2	20.2	16.8	15.1											
10	480.0	240.0	160.0	120.0	96.0	80.0	68.6	60.0	53.3	48.0	40.0	32.0	26.7	24.0	19.2	16.0	13.7								
8	764.0	382.0	255.0	191.0	153.0	127.0	109.0	95.5	84.9	76.4	63.7	51.0	42.5	38.3	30.6	25.5	21.8	19.1	17.0						
6	1,217.0	608.0	405.0	304.0	243.0	202.0	174.0	152.0	135.0	121.0	101.0	81.0	67.5	60.8	48.6	40.5	34.7	30.4	27.0	22.1					
5	1,533.0	766.0	511.0	383.0	307.0	255.0	219.0	192.0	170.0	153.0	128.0	102.0	85.0	76.6	61.3	51.1	43.8	38.4	34.1	27.8	23.6	20.4			
4	1,933.0	966.0	644.0	483.0	387.0	322.0	276.0	242.0	215.0	193.0	161.0	129.0	107.0	96.7	77.3	64.4	55.1	48.3	43.0	35.1	29.7	25.8	22.7		
3	2,437.0	1,219.0	812.0	609.0	487.0	406.0	348.0	305.0	271.0	244.0	203.0	162.0	135.0	122.0	97.4	81.1	69.6	60.9	54.0	44.3	37.5	32.5	28.7	25.7	24.1
2			1,024.0	768.0	615.0	512.0	439.0	384.0	341.0	307.0	257.0	205.0	171.0	154.0	123.0	102.0	87.9	76.9	68.3	55.9	47.3	41.0	36.2	32.4	30.7
1			1,291.0	969.0	775.0	646.0	554.0	484.0	431.0	387.0	323.0	258.0	215.0	194.0	155.0	129.0	111.0	96.9	86.0	70.3	59.6	51.7	45.6	40.8	38.7
0				1,222.0	978.0	815.0	698.0	611.0	515.0	489.0	407.0	326.0	272.0	245.0	195.0	163.0	140.0	122.0	109.0	88.7	75.2	65.1	57.5	51.4	48.9
00					1,232.0	1,027.0	880.0	770.0	685.0	616.0	513.0	410.0	342.0	308.0	246.0	205.0	176.0	154.0	137.0	112.0	94.8	820.0	72.5	64.8	61.6
000						1,295.0	1,110.0	971.0	863.0	777.0	648.0	518.0	432.0	388.0	311.0	259.0	222.0	194.0	173.0	141.0	119.0	104.0	91.4	81.7	77.7
0000							1,400.0	1,225.0	1,089.0	980.0	817.0	653.0	544.0	490.0	392.0	326.0	280.0	245.0	218.0	178.0	151.0	131.0	115.0	103.0	98.0

Distance in Feet.

Table II is very convenient because it gives the distance exactly corresponding to the required drop. To use it, divide the number of amperes transmitted by the number of volts drop desired. Find the nearest number to this result in the line of amperes; below this find the distance in feet most nearly corresponding to the given distance; to the left of this, in the column of wire sizes, is given the number of the required wire.

For example, to find the size of wire to transmit 15 amperes 140 feet with 3 volts loss, divide 15 by 3 and find the quotient 5 in the line of amperes. In the column below, we find the nearest distance 153, and to the left of this the size of wire required, No. 8.

13. Probably the most convenient of all methods of calculation, after one is accustomed to using it, is the graphical method, in which amperes and distances are laid off at right angles to one another, and the wires corresponding to different values of these quantities, for the loss of 1 volt, are represented by curved lines. Figs. 2 and 3 are diagrams of this kind. Notice that every wire curve is dotted for a short distance for currents larger than the maximum allowed by the Underwriters' rules for that size of wire. In determining the size of wire from these diagrams, do not use the dotted portions of the curves. If a point should come near one of the dotted sections, use the next larger size of wire.

To use such a diagram, find the point where the lines representing amperes and given distance intersect, and take the wire indicated by the wire line nearest this point. Unless the wire line is very close, take the larger wire of the two lines on each side of the intersection point.

For example, to find the wire required for 7 volts loss in a distance of 125 feet, with 21 amperes, we divide 21 by 7, which gives 3; where the line of 3 amperes intersects the line of 125 feet, we are between the lines representing No. 10 and No. 12 wire. The point lies about midway between the two curves, and hence we use the larger size of wire, No. 10.

14. In calculating the sizes of wires for 52-, 104-, 220-, or 250-volt work, or for any intermediate voltage, it must

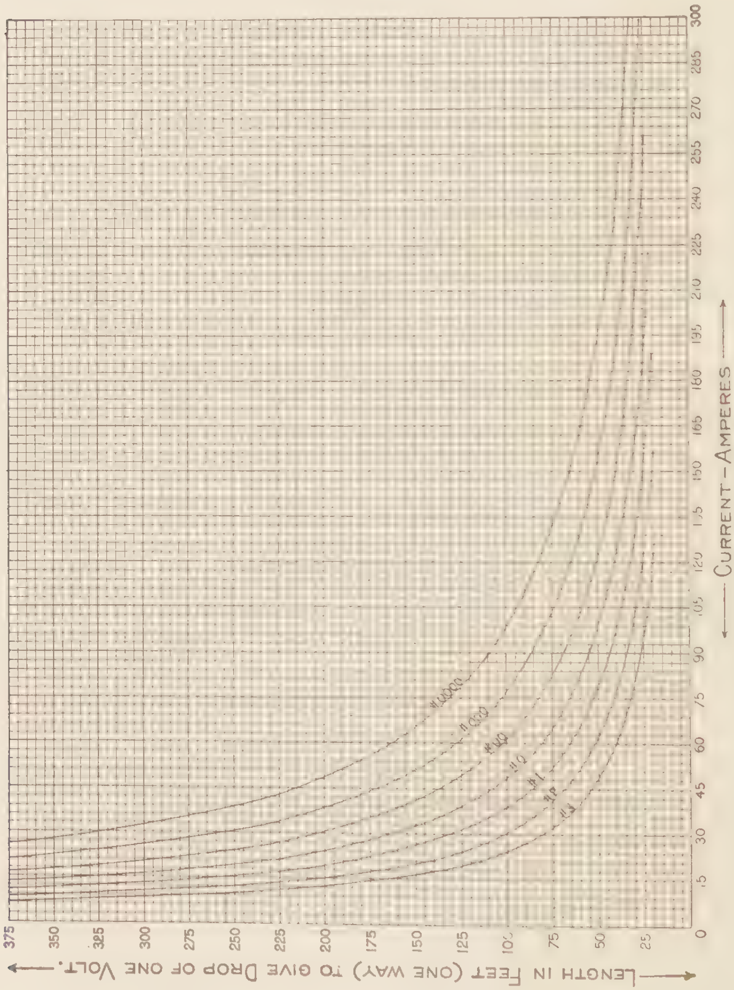


FIG. 2

be borne in mind that lamps burning on lower voltages than 110 take more current, and those burning on higher voltages take less current. An ampere per lamp for 52-volt lamps, $\frac{1}{2}$ ampere per lamp for 104- or 110-volt lamps, and

.3 ampere per lamp for 220-volt lamps is a safe basis for calculations where good lamps are used. Also, it must be

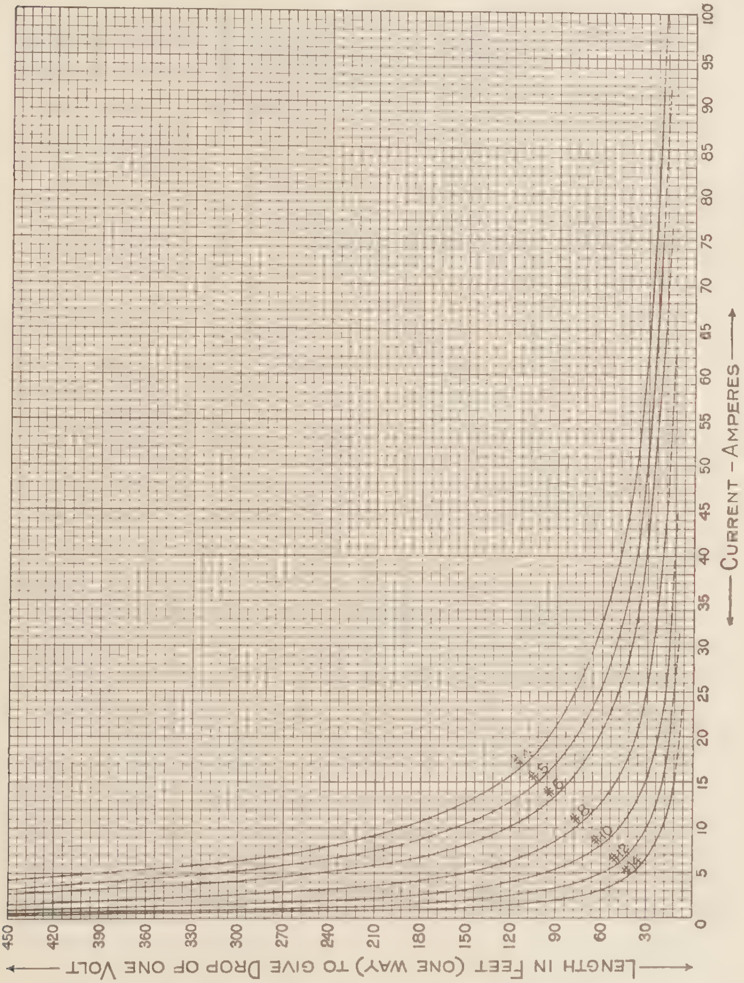


FIG. 3.

remembered that "per cent. drop" and "volts drop" are very different things, as set down in Table III.

The figures given in the table represent the actual drop in volts for the line voltage at the top of each column, with

the percentages of drop given in the left-hand column. For example, a drop of 5 per cent. on a voltage of 150 would give 7.5 volts.

TABLE III.

Per Cent. Drop.	Line Voltages.					
	52	104	110	150	220	250
1	.52	1.04	1.1	1.5	2.2	2.5
2	1.04	2.08	2.2	3.0	4.4	5.0
3	1.56	3.12	3.3	4.5	6.6	7.5
5	2.60	5.20	5.5	7.5	11.0	12.5
7	3.64	7.28	7.7	10.5	15.4	17.5
10	5.20	10.40	11.0	15.0	22.0	25.0
15	7.80	15.60	16.5	22.5	33.0	37.5

FUSE PROTECTION FOR CONDUCTORS IN MULTIPLE.

15. It is frequently desirable to run two or more small wires in multiple, instead of one large wire or cable, either for convenience in handling the wires, to obtain a certain carrying capacity with the use of less copper, to use material that happens to be at hand, or for other reasons. When two or more wires are run thus and are connected together at their ends, separate fuses must be placed in series with each wire, and not one fuse for all the wires in multiple.

Fig. 4 (*a*) and (*b*) illustrates the correct and the incorrect methods of connecting such cables. Multiple conductors of this kind may sometimes be used to advantage in overhauling or remodeling old work, where the wires originally installed are too small, and in wiring an old building by the use of molding, where large wires cannot be handled without defacing the walls.

For convenience in comparing the conductivities of wires, Table IV is given. As an illustration, it is seen from the table that instead of a single No. 2 wire we might use four No. 6 wires; two No. 5; four No. 8; etc. Of course, nothing smaller than No. 14 can be used for interior wiring.

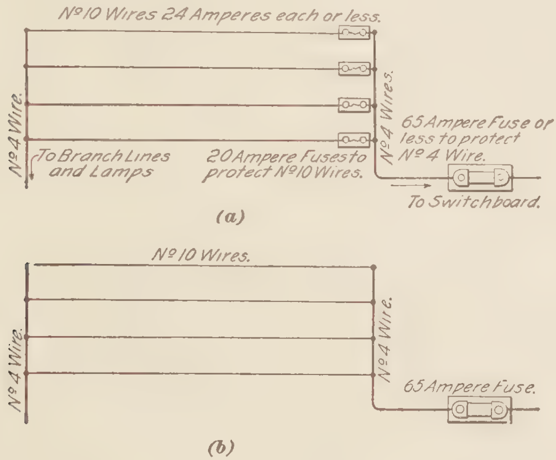


FIG. 4.

The conductivity is directly proportional to the total cross-section of all the conductors in multiple, and the total resistance is inversely proportional to the total cross-section.

16. Circuits of several wires in multiple are sometimes run where a large drop in voltage is not objectionable, but where a single wire small enough to produce that drop will not carry the current safely. Two or more small wires will safely carry more current than one large wire of equivalent cross-section, because two small wires have a greater surface area from which the heat can escape than has one wire of twice the cross-section. For instance, suppose it is desired to run wires in molding to secure a drop of 4 volts with 65 amperes over a distance of 100 feet. Calculating the required size of wire by means of Table II, we see that No. 5 will give the required drop. But No. 5 rubber-covered

TABLE IV.

EQUIVALENT CROSS-SECTION OF WIRES.

Number of Wire, B. & S. Gauge.	Equivalent Cross-Section, in Terms of Smaller Wires.								
0000	00 + 1	2—0	4—3	8—6	16—9	32—12	64—15	128—18	1 + 2 + 2
000	0 + 2	2—1	4—4	8—7	16—10	32—13	64—16	128—19	2 + 3 + 3
00	1 + 3	2—2	4—5	8—8	16—11	32—14	64—17	128—20	3 + 4 + 4
0	2 + 4	2—3	4—6	8—9	16—12	32—15	64—18		4 + 5 + 5
1	3 + 5	2—4	4—7	8—10	16—13	32—16	64—19		5 + 6 + 6
2	4 + 6	2—5	4—8	8—11	16—14	32—17	64—20		6 + 7 + 7
3	5 + 7	2—6	4—9	8—12	16—15	32—18			7 + 8 + 8
4	6 + 8	2—7	4—10	8—13	16—16	32—19			8 + 9 + 9
5	7 + 9	2—8	4—11	8—14	16—17	32—20			9 + 10 + 10
6	8 + 10	2—9	4—12	8—15	16—18				10 + 11 + 11
8	10 + 12	2—11	4—14	8—17	16—20				
10	12 + 14	2—13	4—16	8—19					
12	14 + 16	2—15	4—18	8—20					
14	16 + 18	2—17	4—20						
16	18 + 20	2—19							

wire will safely carry only 54 amperes, while 65 amperes are to be transmitted. By using two No. 8 wires, which are equivalent in cross-section to one No. 5, we can safely carry the current with the specified drop. If the current were still greater, we could use one No. 8 and two No. 10 wires with about the same results. However, such arrangements to secure a drop are only used in emergencies or under special conditions, and are usually only temporary expedients.

17. Calculation of Wires in Multiple.—If a number of wires are connected in multiple,

$$\frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} + \text{etc.},$$

where R is the combined resistance of the wires and r_1, r_2, r_3, etc. their separate resistances.

To apply this formula, suppose that a wireman at a distance from a supply house has on hand a large amount of No. 12 wire, but no larger wire, and that he desires to run mains to carry a current of 40 amperes 150 feet with 3 volts loss. How many No. 12 wires should be connected in multiple to secure this result?

$$\text{Resistance of line} = \frac{\text{volts drop}}{\text{amperes}} = \tfrac{3}{40} = .075 \text{ ohm}.$$

The total length of line $= 150 \times 2 = 300$, or .3 thousand feet. The resistance of the line per 1,000 feet $= \frac{.075}{.3}$ $= .25$ ohm. Now, 1,000 feet of No. 12 wire has a resistance of about 1.586 ohms. All the wires in multiple are to be No. 12; hence, $r_1 = r_2 = r_3 = 1.586$.

Let $x =$ the number of No. 12 wires required; then in the formula given above, we have $R = .25$, and since r_1, r_2, r_3, etc. are all equal, $\frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} + \text{etc.}$ must equal $\frac{x}{1.586}$. Hence, $\frac{1}{.25} = \frac{x}{1.586}$, whence $x = 6.3$. Six No. 12 wires in multiple will answer the purpose.

Let us take another example. In an old building, wired with too much drop, it is desired to reenforce the mains so as to reduce the drop to 2 volts. A circuit of No. 8 wire carrying 20 amperes a distance of 200 feet is to be reenforced. What size of wire should be used?

Total resistance of the line should be $\frac{2}{20} = .1$ ohm. Since this line, whose resistance is to be .1 ohm, is 400 feet long both ways, then the resistance per 1,000 feet must be $.1 \times \frac{1000}{400} = .25$ ohm. The resistance of a No. 8 wire per 1,000 feet = .627 ohm. Let $r_1 = .627$ and $r_2 =$ the resistance per 1,000 feet of the wire required.

Then we have, by substituting in the formula $\frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2}$,

$$\frac{1}{.25} = \frac{1}{.627} + \frac{1}{r_2} \text{ or } \frac{1}{r_2} = \frac{1}{.25} - \frac{1}{.627} = 2.41; \text{ hence, } r_2 = .415.$$

A No. 6 wire of which the resistance is .394 ohm per 1,000 feet most nearly meets this requirement.

WIRING IN DAMP PLACES.

18. Where wiring is done in damp places, special precautions must be taken and special rules observed. The following Underwriters' rules apply to this work:

Wires—

In damp places, such as breweries, sugar houses, packing houses, stables, dye houses, paper or pulp mills, or buildings especially liable to moisture, or acid, or other fumes liable to injure the wires or their insulation, except where used for pendants:

a. Must have an *approved* rubber-insulating covering.

b. Must be rigidly supported on non-combustible, non-absorptive insulators that separate the wire at least 1 inch from the surface wired over, and wires must be kept apart at least 2½ inches for voltages up to 300 and 4 inches for higher voltages.

Rigid supporting requires under ordinary conditions, where wiring over flat surfaces, supports at least every 4½ feet. If the wires are liable to be disturbed, the distance

between supports should be shortened. In buildings of mill construction, mains of No. 8 B. & S. wire or over, where not liable to be disturbed, may be separated about 4 inches, and run from timber to timber, not breaking around, and may be supported at each timber only.

c. Must have no joints or splices.

Sockets.—

a. In rooms where inflammable gases may exist, the incandescent lamp and socket must be enclosed in a vapor-tight globe and supported on a pipe hanger, wired with *approved* rubber-covered wire soldered directly to the circuit.

b. In damp or wet places or over specially inflammable stuff, waterproof sockets must be used.

When waterproof sockets are used, they should be hung by separate stranded rubber-covered wires, not smaller than No. 14 B. & S., which should preferably be twisted together when the drop is over 3 feet. These wires should be soldered direct to the circuit wires, but supported independently of them.

19. Fig. 5 shows a waterproof globe for use where inflammable gases may exist. In wiring damp cellars, it is especially desirable to have the lamps divided among several small circuits, so that the blowing of a fuse will not put out many lamps. In such work, rosettes should never be used, but the drop wires should be soldered direct to, but preferably not supported by, the line wires, and the joints should be thoroughly wrapped with insulating tape. The cut-outs should be placed outside the cellars, in a dry place if possible, otherwise they should be placed in waterproof boxes.

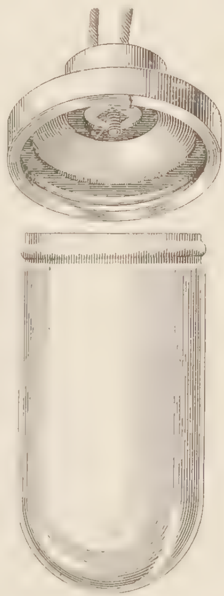


FIG. 5.

20. Rubber-Covered Wire.—*In all kinds of work, except open work in dry places, rubber-covered wire must be used.* The Underwriters require it to comply with the following specifications:

Rubber-Covered Wire.—

a. Copper for conductors must be thoroughly tinned.

Insulation for voltages between 0 and 600:

b. Must be of rubber or other approved substance and be of a thickness not less than that given in the following table for B. & S. gauge sizes:

From	18 to	16, inclusive,	$\frac{1}{32}''$
From	14 to	8, inclusive,	$\frac{3}{64}''$
From	7 to	2, inclusive,	$\frac{1}{16}''$
From	1 to	0000, inclusive,	$\frac{5}{64}''$
From	0000 to	500,000, C. M.	$\frac{3}{32}''$
From	500,000 to	1,000,000, C. M.	$\frac{7}{64}''$
Larger than		1,000,000, C. M.	$\frac{1}{8}''$

Measurements of insulating wall are to be made at the thinnest portion.

c. The completed coverings must show an insulation resistance of at least 100 megohms (100,000,000 ohms) per mile during 30 days' immersion in water at 70° F.

d. Each foot of the completed covering must show a dielectric strength sufficient to resist throughout 5 minutes the application of an electromotive force of 3,000 volts per $\frac{1}{64}$ inch thickness of insulation under the following conditions:

The source of alternating electromotive force shall be a transformer of at least 1 kilowatt capacity. The application of the electromotive force shall first be made at 4,000 volts for 5 minutes and then the voltage increased by steps of not over 3,000 volts, each held for 5 minutes, until the rupture of the insulation occurs. The tests for dielectric strength shall be made on a sample of wire that has been immersed for 72 hours in water, 1 foot of which is submerged in a conducting liquid held in a metal trough, one of the transformer terminals being connected to the copper of the wire and the other to the metal of the trough.

Tests by the Underwriters are made on the products of the various manufacturers from time to time, and the names of those wires that are acceptable, as complying with this standard, can be learned from them.

CONCEALED KNOB-AND-TUBE WORK.

21. The most common way of concealing wires in a building is to run them through the joists between the floors and ceilings and through studding partitions, and to insulate them by means of porcelain knobs and tubes, as shown in Fig. 6. The holes should not be closer together than is allowed by the Underwriters' rules, as given below, and the tubes should fit tightly in the holes. When the holes are not horizontal, but are bored from above or below obliquely, the tubes should be put in with their heads on the high side, so that they cannot fall or slide out; and when tubes are placed so that there is any strain upon them, their heads must be so placed that the tubes cannot slip. Holes should be bored of such a size that the tubes can be inserted by driving lightly. Do not make the holes too small or there will be danger of breaking the tubes. Holes must be bored sufficiently far away from the floors and ceilings to be out of reach of nails that may be driven into the joists after the work is concealed. Bushings must be long enough to reach all the way through the joists, with $\frac{1}{2}$-inch projection.

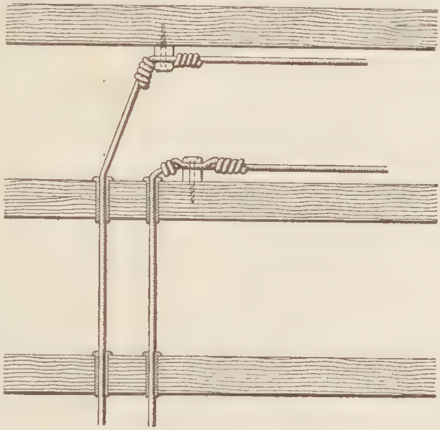


FIG. 6.

22. Where wires come through the plaster to outlets or cut-outs, they must be protected by proper bushings or outlet blocks. Special porcelain fittings have been designed for this purpose by several manufacturers. Careless work is often done at outlets, with the result that a job that is otherwise well put up will show poor insulation. The same outlets are very often used both for gas and electricity, and

if the wires are not well protected when brought out, a ground on the gas pipe will result.

Fig. 7 shows the method of bringing out the wires when using curved, porcelain outlet tubes. The tubes are bound firmly to the gas pipe with tape and the curved ends hold the wire away from the pipe. Where there is no gas pipe, plain, straight tubes may be used if they are fixed so that they will stay in place. Fig. 8 (*a*) and (*b*) shows two methods of bringing out side outlets by using special outlet fittings. In (*a*) the outlet tubes are fastened to the studding, in (*b*) the block is fastened to

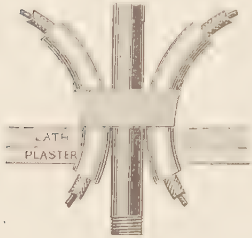
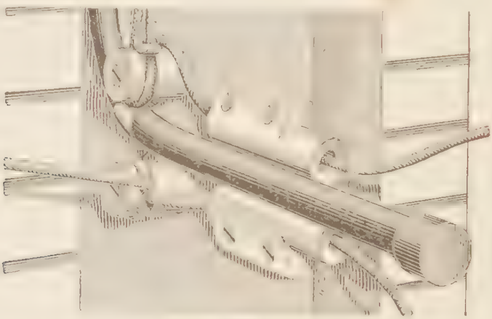


FIG. 7.



(*a*)

(*b*)

FIG. 8.

the lath. In bringing out wires through either the walls or

ceilings, see that there is no danger of their coming in contact with gas pipes or plaster.

23. For running wires parallel to joists, knobs are generally used because they make it possible to keep the wires well separated. The following rules apply to this kind of work:

Wires—

For concealed "knob-and-tube" work:

a. Must have an *approved* rubber-insulating covering.

b. Must be rigidly supported on non-combustible, non-absorptive insulators that separate the wire at least 1 inch from the surface wired over, and must be kept at least 10 inches apart, and, when possible, should be run singly on separate timbers or studding.

c. Must be separated from contact with the walls, floor timbers, and partitions through which they may pass by non-combustible, non-absorptive insulating tubes, such as glass or porcelain.

Rigid supporting requires under ordinary conditions, where wiring along flat surfaces, supports at least every $4\frac{1}{2}$ feet. If the wires are liable to be disturbed, the distance between supports should be shortened.

When, from the nature of the case, it is impossible to place concealed wiring on non-combustible supports of glass or porcelain, an approved armored cable with single or twin conductors may be used where the difference of potential between conductors is not over 300 volts, provided it is installed without joints between outlets, and the cable armor properly enters all fittings and is rigidly secured in place; or if the difference of potential between wires is not over 300 volts, and if the wires are not exposed to moisture, they may be fished on the loop system if separately encased throughout in flexible or approved conduit.

d. Conduit, even when used in connection with concealed knob, tube, and conduit work, must be continuous from outlet to outlet, and comply with rules covering interior conduits.

e. Must at outlets for combination fixtures (i. e., fixtures for both gas and electric light) be bushed with flexible insulating tubes extending in continuous lengths from the last porcelain support to

> 1 inch beyond the outlet, except that an approved outlet insulator may be used. At outlets where there are no gas pipes, either this class of construction or porcelain tubes may be used.

An armored cable will rarely be required in connection with concealed knob-and-tube work in a new building, where everything is accessible; but in an old building, where there

FIG. 9.

are objections to tearing up floors to insert wires, it may be used to considerable advantage. Fig. 9 shows such an armored twin conductor suitable for this purpose, which means that it complies with the following specifications:

Armored Cable.—

> *a*. The armor of such cables must be at least equal in thickness and of equal strength to resist penetration by nails, etc. as the armor of metal coverings of metal conduits.
>
> *b*. The conductors in same, single wire or twin conductors, must have a rubber-insulating covering; any filler used to secure a round exterior must be impregnated with a moisture repellent, and the whole bunch of conductors and fillers must have a separate exterior covering.

Such cables may be used to wire buildings without any porcelain tubes whatever, as the insulation required is very high; but the system requires special fittings and tools for installing it and has not yet come into very extensive use, probably on account of its expense.

24. The protected flexible cord, of the same style, is a very convenient article to use in wiring offices, banks, etc., where small conductors must be carried behind desks or fastened to iron or cabinetwork, and in many other places where ordinary cords will not do and will not be permitted.

25. The calculations for concealed wiring are the same as for open work; but it must be remembered that rubber-covered wires are not to be allowed to carry as much current as weather-proof wires, as shown by the Underwriters' Table of Carrying Capacities.

26. Use of Cabinets and Panel Boards.—For concealed work, the **closet,** or **cabinet,** system of distribution is now universally used. In this method of wiring, the mains are run to *cabinets* or *panel boards* set in the wall, and from these the lines running to the lamps are distributed. Many different styles of these panel boards are manufactured, and the style used will depend largely on the size and allowable cost of the installation. For the cheaper class of work, the cut-outs may be grouped together and placed in a cabinet formed in the wall. This cabinet should be neatly lined with $\frac{1}{8}$-inch asbestos; and where the wires pass into and out of the sides or bottom, they should be bushed with porcelain tubes. A neat glass or asbestos-lined door should be provided. A cabinet made in this way is inexpensive and safe and meets the requirements of the Underwriters. In more expensive installations, the panel boards are made of slate or marble and the sides and bottoms of the boxes are also of slate or marble.

Fig. 10 will give an idea as to the essential parts of a panel board. In this case the two wires are run in a conduit. The box is mounted in the wall and consists of two compartments, the inner compartment

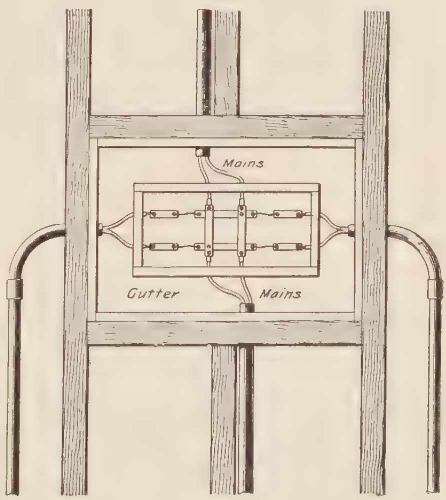


FIG. 10.

containing the panel board, and the outer one, or *gutter*, as it is sometimes called. All boxes are not provided with this gutter, but the best ones are, as it gives a convenient space in which to arrange the wires in case they should not come to the box in the best order for connecting up. The box is made of slate or marble slabs. The trim around the door covers the gutter; it should be put up with screws so that it may be removed if necessary.

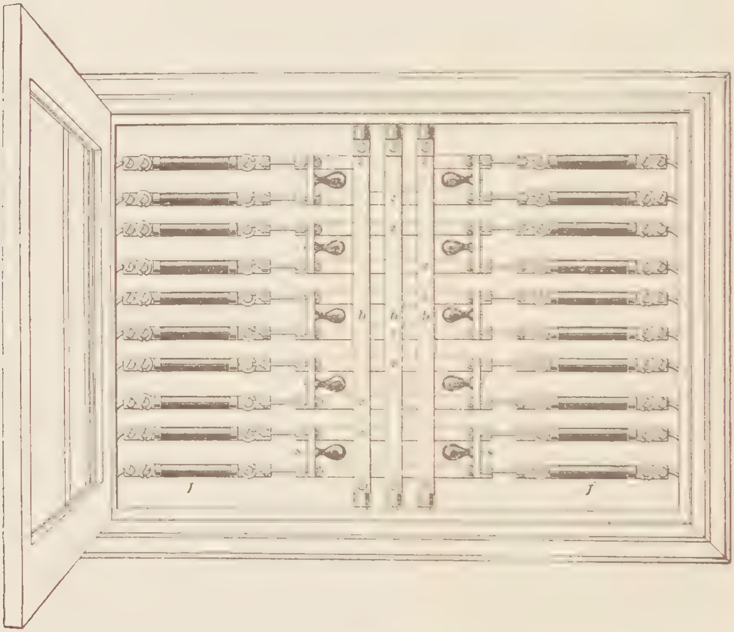


FIG. 11.

The mains usually pass through the panels vertically and are connected to bars from which the various lamp circuits branch out sidewise. Fuses are inserted in each side of each circuit, and switches are in some cases also provided; though frequently the panel board carries fuses only.

Fig. 11 shows a panel board equipped with double-pole switches *s* and enclosed fuses *f*. Ten branch circuits are accommodated and the three-wire vertical mains are attached

to the copper bars *b*, *b*, *b*; the mains enter at the bottom and pass out at the top to the floor above.

27. Instead of building a wooden box in the wall to take the slate or marble pieces that go to make up the cabinet, iron or steel boxes are now used in much of the better class of work. Fig. 12 shows a cabinet of this kind ready to be set into the wall and connected up. It is made of a sheet-steel box *a*, whose sides and top are lined inside with $\frac{1}{4}$-inch

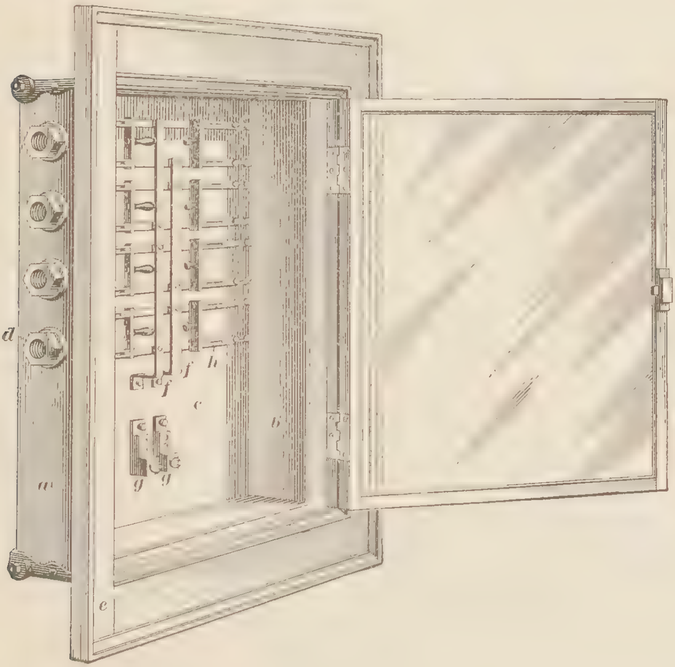


FIG. 12.

slate slabs *b*. The panel board *c* constitutes the back of the box. In the figure the openings *d* for the branch circuits are arranged to take conduits, but the same style of box can be provided with porcelain bushings for wiring done on porcelain. If it is necessary to have a distributing space, or gutter, around the cabinet, it is covered

by the trim *e* projecting around the box. The two-wire vertical mains are connected to terminals *g*, *g* and, through the main fuses, to the bars *f*, *f*. Each branch circuit is provided with fuse terminals and a knife switch *h*.

Fig. 13 (*a*) shows a style of panel board that uses a special kind of fuse holder that serves the purpose of a switch when it is desired to disconnect any circuit. Panel boards using combination fuse holders have been adopted quite largely,

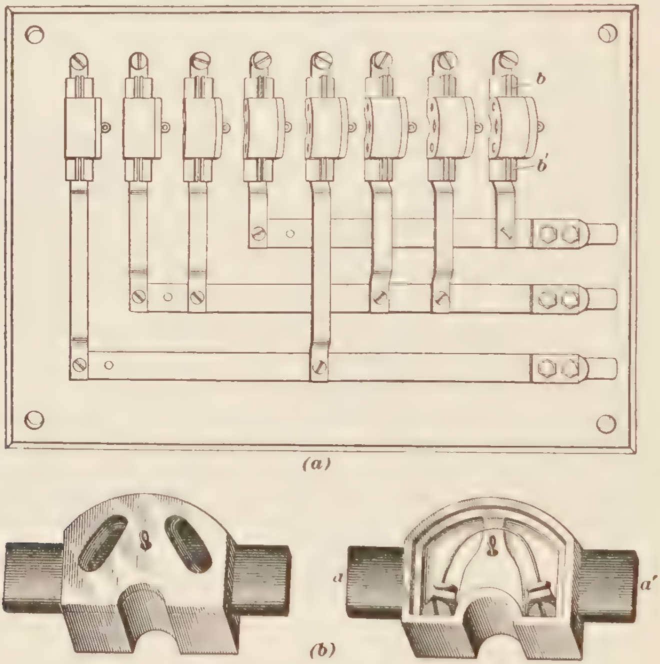


FIG. 13.

for they have one advantage in that the holder may be entirely removed from the board when the fuse is being replaced, or another reserve holder may be put in instead of the one removed. Fig. 13 (*b*) shows one of these holders. It is held in place by the clips *b*, *b'* that receive the blades *a*, *a'*. Fig. 14 shows a plain two-wire board for four branch circuits; it is equipped with Edison fuse plugs and

has no switches. The above will give a general idea as to the construction of these boards. They are made in all sorts of combinations and, in fact, are usually made to order for any given job. In large wiring systems, the

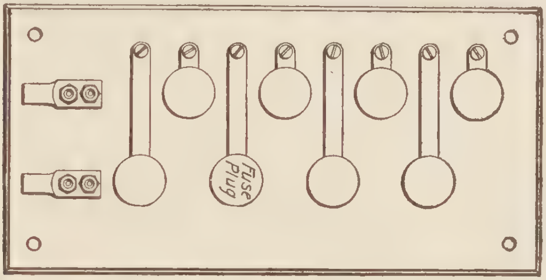


FIG. 14.

design of the cut-out closets, or cabinets, is a matter of great importance, and the location of these closets is equally important; they should be placed in a position where they can be readily reached.

28. The following Underwriters' rules relate to cut-out cabinets:

Cut-Out Cabinets—

Must be so constructed and cut-outs so arranged as to obviate any danger of the melted fuse metal coming in contact with any substance that might be ignited thereby.

The following specifications should be followed:

Material.—

a. Boxes may be of marble, slate, or wood. If wood is used, the inside of the box must be lined with non-combustible material, such as slate or asbestos board. If asbestos board is used, it must be at least $\frac{1}{8}$ inch in thickness, must be neatly put on, and firmly secured in place by shellac and tacks.

Door.—

b. The door must close against a rabbet, so as to be perfectly dust-tight. Strong hinges and a strong hook or catch are required. Glass doors

must be glazed with heavy plate glass, not less than $\frac{3}{16}$ inch in thickness and panes not to exceed 1 foot in width. A space of several inches should be allowed between the fuses and the door, especially when glass is used. This is necessary to prevent cracking or breaking by the severe blow and intense heat that may be produced under some conditions.

Bushings.—

c. Bushings through which wires enter must tightly fit the holes in the box and must be of approved construction.

Wires should tightly fit the bushings, tape being used to build up the wire, if necessary, so as to keep out the dust.

WIRING A DWELLING HOUSE.

29. In laying out the wiring for a dwelling house, the first thing to do is to select a place to locate the cut-out cabinets. In many dwelling houses, only one cut-out cabinet may be necessary, but in houses designed to be occupied by more than one tenant, a cut-out cabinet should be installed for each tenant. In large houses, it is often convenient to have a cut-out cabinet on each floor, with vertical mains running through them from the top to the bottom of the house. If only one distributing point is used, it should be either in the cellar or attic and risers run to the different floors. If it is known that the wires are to enter the building in the cellar, then the distributing center should be located there; if the wires enter in the attic, the distributing point should be located there. This assumes that vertical risers are run from the distributing center to feed the various floors. In case a single pair of vertical mains is used with the circuits branching off on each floor, the mains may be run from the top to the bottom of the house and the current supplied from either end.

30. No matter what arrangement is adopted for distributing the current, the distributing centers, or cut-out

cabinets, should be in or near a partition that is located so as to make the running of risers easy. They should also be as near the center of the building as possible and on an inside wall, so as to guard against dampness.

31. Figs. 15 and 16 show two floors of a typical dwelling The distributing points are located in the hallway near the center of the house. It is usually advisable to locate the cut-outs in a hallway, if possible, because such location is generally central and easy to get at. The various branch circuits on the plans are indicated by single lines, although each line represents two wires. The wiring is supposed to be done on the ordinary concealed knob-and-tube system. The circuits are arranged so that there will be not more than 10 lights on any one circuit. Switches are placed on the side walls as shown at *s*. The switch for controlling the hall lights should be placed at some convenient point near the door, so that the lights may be turned on when entering the building. It is sometimes convenient to have another switch at the head of the stairs for controlling the hall light, so that the light may be turned on or off from either above or below. This requires the use of three-point switches, and the connections necessary will be explained later. In the plans, double-pole switches are indicated. Single-pole switches may, however, be used when not over 660 watts are controlled They are cheaper to install than the double-pole switches.

32. Laying Out Circuits.—In laying out the various branch circuits, the first thing to do is to locate the lights on the plan and then group these lights for the different circuits, so that there will not be more than 10 or 12 lights on each one. After this is done, the lines may be marked; in doing this, due regard should be given to the direction in which the joists run, so that the wire may be put in with as little boring and cutting as possible. Run parallel to the beams wherever it can be done, even if it does take a little more wire. The best time to wire the building is after the

floorbeams and studding are in place, but before any lathing or plastering has been done. In Fig. 15, four circuits

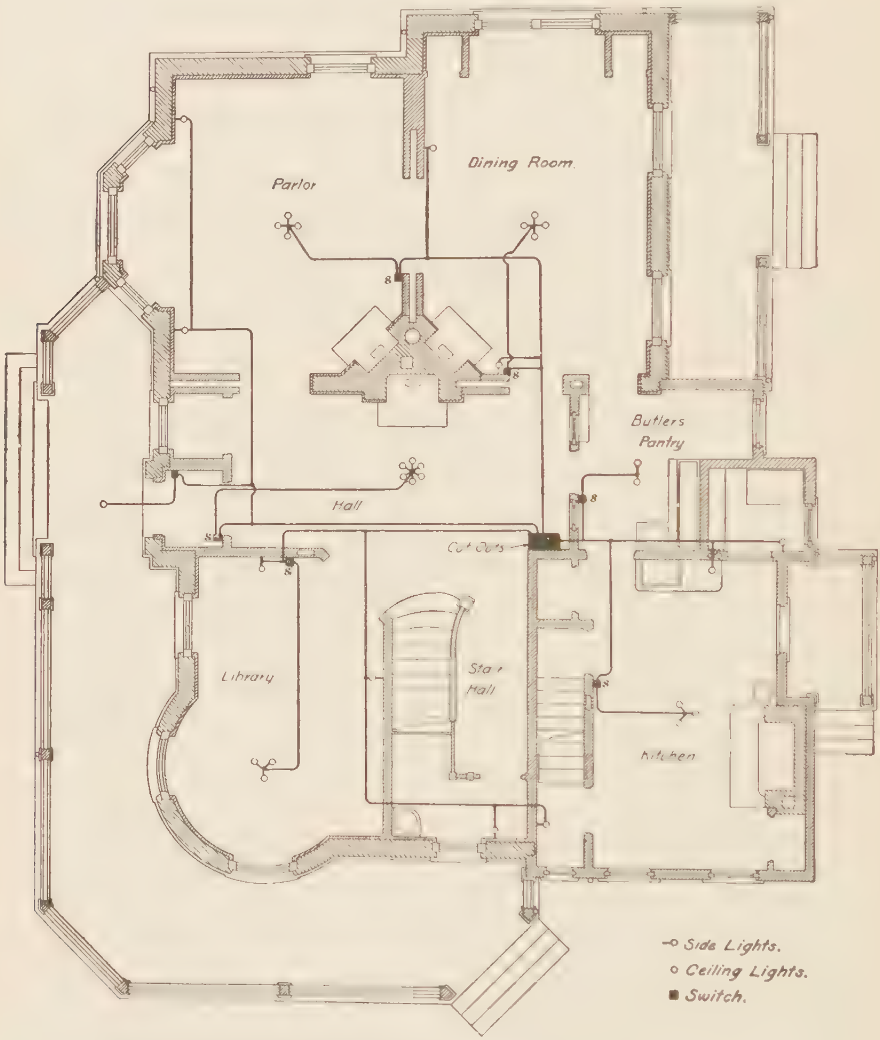


FIG. 15.

are provided, all terminating in the cut-out cabinet in the hall, where they are attached to the vertical mains. For

the second floor, Fig. 16, three circuits are sufficient. No. 14 wire is used for all these circuits. It will be found

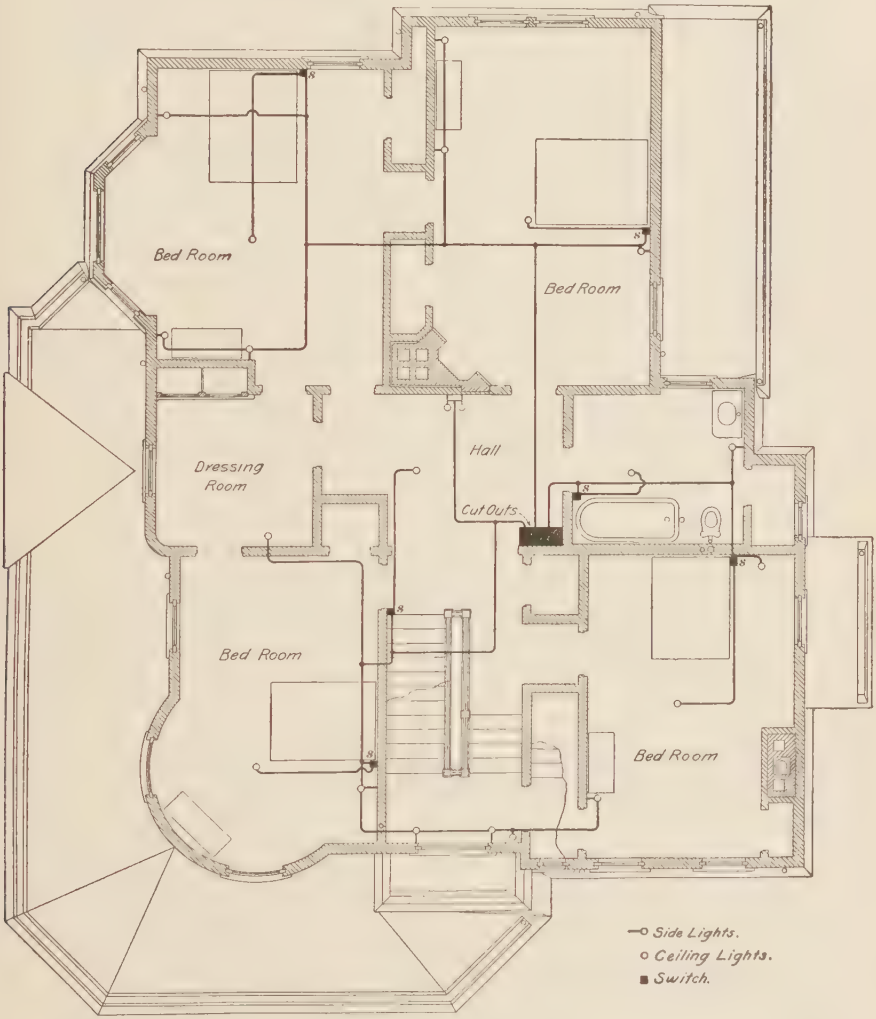


FIG. 16.

that No. 14 wire (the smallest that the Underwriters allow) is large enough for any of the branch circuits met with in

ordinary house-wiring work. The number of lights per circuit is small and the distances short, so that No. 14 will carry the current with but a small drop in voltage. This assumes that from 100 to 110 volts pressure is to be used. If 52 volts is the pressure of the supply, it is best to figure out the drop for each circuit. In most cases, it will be found advisable to use No. 12 wire. On new work 52 volts is seldom used, and in fact in work already installed, electric-light companies are changing the lamps over to 104 or 110 volts. In nearly all cases, therefore, No. 14 wire (rubber-covered for this kind of work) is sufficiently large for the branch circuits.

33. The Mains.—If vertical mains are used, the current that they will carry will be less at one end than at the other, because current is taken off at the different floors. It is usually advisable, however, to make the mains the same size all through an ordinary house, because it costs but little more and enables the current to be supplied from either end. Of course, in large buildings it would not pay to do this. In large buildings it is customary to have a number of risers feeding different sections of the building, all of which run to a common distributing point, usually located in the basement. The mains must, of course, be designed to carry the current in accordance with the Underwriters' requirements or to limit the drop to the allowable amount if the wire required by the Underwriters will give too much drop. In the house under consideration, suppose we have a total of 60 lamps. The current in the mains will then be 30 amperes, and we will need at least a No. 8 wire to satisfy the Underwriters' requirements.

By referring to Table II, it is found that No. 8 wire will carry 30 amperes a distance of 25.5 feet with a drop of 1 volt. For a building of this kind, the drop from the point where the current enters the building to the lamps should not exceed 2 to 2.5 volts. The drop in the branch circuits will be very small, but it would be advisable to put in No. 6

mains, as the difference in first cost will be but little. It is the usual practice to make the mains of liberal cross-section. For a house of this size No. 4 would often be used, although it does not need to be as large as this so far as drop is concerned.

34. Main Switch, Cut-Out, and Meter.—At a convenient point near the place that the wires enter the building, a main cut-out and switch must be placed, as required by the Underwriters. The cut-out should be placed nearest the point of entry, the switch next to it, and the meter last. Never permit the meter to be installed between the switch and the cut-out, as in that case it may register a small amount each day, even if the switch be open. It is best to use a knife-blade switch at the entrance to the building, and this switch should be so placed that when opened it will not tend to fall closed of its own accord.

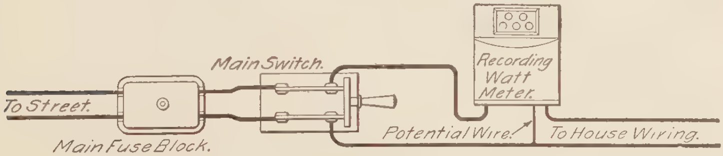


FIG. 17.

The best arrangement of the wires for the meter will depend to some extent on the type of meter used. In a great many cases, however, the wires enter the left-hand side of the meter and pass out at the right. Fig. 17 represents a typical arrangement of main fuses, switch, and meter.

Most recording electric meters consist of a small electric motor, the revolving part of which turns on jeweled bearings and is connected to a train of gears and dials. The motor is governed by means of retarding devices, so that it runs at a speed accurately proportional to the load. Some meters read in ampere-hours, others in watt-hours,

Most of those now installed read in watt-hours and are provided with two coils, one of which is connected in series with the circuit, like an ammeter, and the other across the circuit, like a voltmeter. The current in the first is, therefore, equal to the current supplied, and the current in the second is proportional to the voltage. The force tending to drive the motor is proportional to the product of the two, i. e., to the watts. The small third wire running into the meter, Fig. 17, is to supply current to the potential coil. With ampere-hour meters, a series coil only is used, and the speed of the meter is proportional to the current and not to the watts.

The voltage of a lighting system is, however, practically constant, so that the watt-hours may be obtained by multiplying the ampere-hours by the voltage without serious error. Reliable meters are made for all voltages and systems and for alternating or direct currents. They are accurate to within 98 per cent. on ordinary loads, but are liable to be out as much as 5 per cent. on small loads, and most meters will take a certain very small load without turning at all. However, they are seldom operated under such conditions.

35. In new buildings, it is often not known what system of electric lighting will be used when the wiring is finished. Owners also desire quite frequently to be able to avail themselves of any advantage in price that may be brought about by competition between different systems. It is, therefore, desirable that each new house shall be wired in such a manner that light may be secured from any system in use—that is, from 52-, 110-, or 220-volt two- or three-wire systems. The following typical specifications cover all the main points necessary for such a piece of work in an ordinary dwelling house.

Other details, such as the location of additional switches, the use of particular kinds of cut-outs, etc., may be added to these specifications if desired. The specifications cover only the concealed work.

Specifications for Concealed Electric-Light Wiring.

For 52-, 110-, or 220-volt systems.

Distribution Closet.

A distribution closet is to be located on some inside wall, in a readily accessible place, on the second floor or the attic, as near the center of the building as possible.

The closet must be lined with asbestos $\frac{1}{8}$ inch thick and fitted with a door covered on the inside with asbestos $\frac{1}{8}$ inch thick.

Circuits.

From this closet separate circuits must be run to the outlets in such a manner that not more than eight 16-candlepower incandescent lamps shall be placed on any circuit. Wherever the number of lamps is not marked on the plans or otherwise specified as greater than here required, pendants shall be considered as intended to carry four lamps each and brackets one lamp each.

Fuse Blocks.

All fuse blocks must be placed in the distribution closet. They must be made of porcelain, must have a breaking distance of $1\frac{1}{2}$ inches, and must be capable of standing the arc caused by the breaking of a 10-ampere fuse on a 220-volt short circuit without cracking the porcelain. Both sides of all lines must be fused.

Wires

All circuits running from the distribution center must be of No. 14 B. & S., or larger, rubber-covered copper wire of a make accepted by the National Board of Fire Underwriters.

Mains.

From the distribution closet to the attic, and also to the basement, a pair of mains must be run, the size of which will depend on the total number of lights in the house, as follows:

17 lamps, or less, .	No. 12 or larger.
18 to 24 lamps, or less, .	No. 10 or larger.
25 to 33 lamps, or less, .	No. 8 or larger.
34 to 46 lamps, or less, .	No. 6 or larger.
47 to 65 lamps, or less, .	No. 4 or larger.

If the house contains more than 65 lamps, it is advisable to have more than one distribution center and pair of mains.

Extra Wire.

A third wire, two sizes smaller than these mains, must also be run from the attic to the basement, through the distribution closet, to make possible the use of the three-wire system.

Manner of Fastening Wires.

Wires running parallel to joists must be fastened on porcelain knobs, placed on different timbers, and kept as far apart as possible. In passing through joists, floors, and other woodwork, the holes must be bushed with porcelain tubes, which must extend at least ½ inch through the wood and be so arranged that their weight will tend to keep them in place rather than to cause them to slip out.

Space Between Wires.

All wires must be kept at least 2½ inches away from one another, from gas or water pipes, iron beams, bell, or annunciator wires, speaking tubes, furnace pipes, and other conducting materials, except at the distribution closet and fixture outlets. Where a wire must cross any such conducting wire, pipe, or material with less clearance, it must have its insulation reenforced by a porcelain tube.

Outlets.

Porcelain tubes (or outlet blocks) must be used at outlets. Special care must be taken to insulate from the gas pipe at outlets.

Running Along Brick or Stone Walls.

Brick and stone walls must be avoided wherever possible. Wherever wires pass along them, they must be encased in approved conduit.

Main-Line Cut-out and Fuse.	There must be supplied and installed by the contractor a main-line cut-out and a quick-break switch, both double pole, to be located in the attic at the end of the feeder lines. These devices must be approved by the Underwriters as capable of breaking the current for the total number of lamps wired, at either 52 or 220 volts. Knife switches, if used, must be so connected that they open downwards and the blades must be "dead" when the switch is open.
Inspection, Certificate, and Payment.	The contractor must notify the Underwriters' Association of the progress of his work in time to have a thorough inspection made (two days before work is concealed at least). He must secure a certificate from that Association stating that the work is suitable for use on 52-, 110-, or 220-volt service, two- or three-wire systems, before any payments shall be made to him.

SWITCHES.

36. Switches located at various points on the walls of rooms are a great convenience and should be installed on all first-class jobs of any magnitude. The single-pole snap switch (for not more than 660 watts) is the simplest and cheapest. It opens one side of the circuit only. Next in frequency of its use is the double-pole snap switch for larger chandeliers or groups of lights. In addition to these, there are a number of special uses of switches to allow lamps to be controlled from two or more points.

37. Control of Lamps From Two Points.—Fig. 18 (a) and (b) shows a switching arrangement for controlling the light or group of lights L from two points A and B. This scheme is used principally in halls where it is desired to control the light from either up or down stairs. It requires two three-point switches S, S', which are here shown as

simple lever switches. There are a number of different makes of switches for this purpose, but the principle of all is the same, though the mechanical details may differ. By comparing the diagrams with whatever make of switch he may have to install, the student should have no difficulty in getting the connections correct. By examining the connections, the student will readily see that the lamps L may be lighted or extinguished from either point. Either method

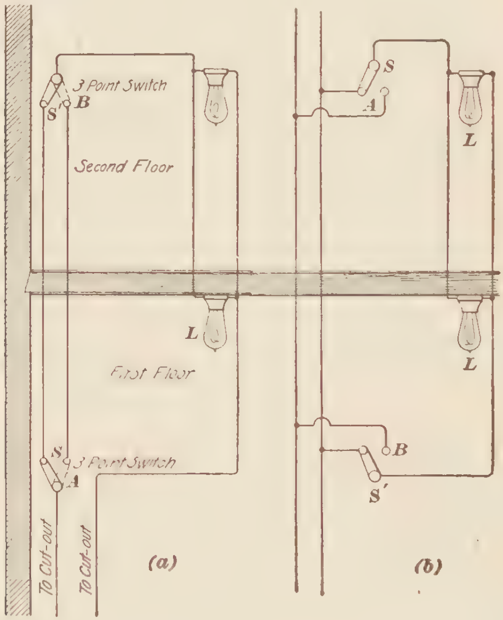


FIG. 18.

of connection (*a*) or (*b*) may be used, and the one that will be most convenient in any given case will depend to some extent on the general layout of the wiring.

A modification of this arrangement is shown in Fig. 19 (*a*) and (*b*). In this case, one of the three-way switches is replaced by a three-way socket. By using a three-way socket on the fixture in connection with a three-way switch on the side wall, a lamp may be turned on or off either at

the socket or at the switch. Both schemes of connection (*a*) and (*b*) accomplish the same result, and the one that is most convenient in any case will depend considerably on the location of the supply mains.

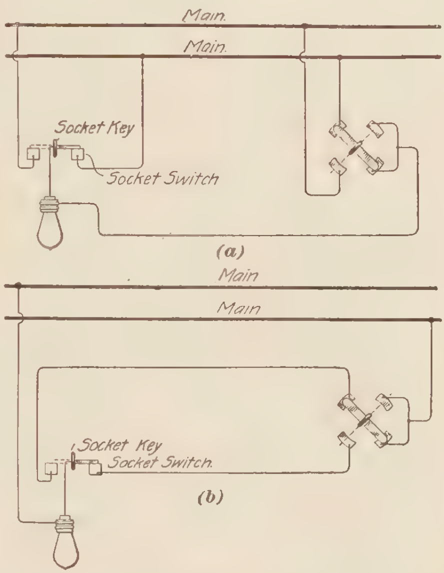


FIG. 19.

38. Control of Lights From Three or More Points.—Lights may be controlled from three stations, as indicated in Fig. 20. It is necessary to use two three-point switches *A*, *C* for the end stations and a four-point switch *B* for the middle station. When *B* is in the position shown, points *1* and *2* are connected together and *3* and *4* are also connected together. When the switch is turned, the former connections are broken and

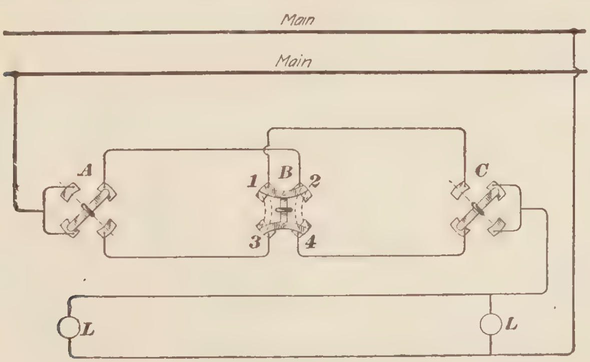


FIG. 20.

points *1* and *3*, *2* and *4* are connected. By tracing out the

path of the current, the student will see that the lights may be turned on and off from any station independently of the position of the switches at the other stations. By cutting in another four-point switch for each additional station in the same way as B, this scheme can be extended to any number of stations desired, and is often used for stairways in flat houses.

39. Electrolier Switches.—These switches usually have three or four points and are used in connection with electroliers to enable a part or the whole of the lights to be operated as desired. Sometimes they are mounted in the electrolier itself. They are made in a variety of forms and the connections necessary are, as a rule, easily understood by an examination of the switch that it is proposed to use.

40. Snap Switches.—Ordinary snap switches are generally of a style similar to that shown in Fig. 21. They are mounted on porcelain bases and the working parts are covered by a metal cap. A switch of this kind is comparatively inexpensive, but it projects from the wall and does not make as neat a job as a switch arranged so that the working parts set into the wall. Moreover, they are always more or less liable to damage and take up space. The other type is known as a **flush** switch. Like snap switches, they are made in a large variety of styles and sizes.

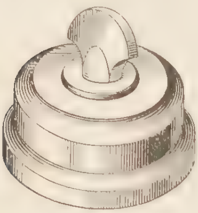


FIG. 21.

Fig. 22 gives an idea as to the arrangement of a flush switch. In this case the switch is operated by pushing the button projecting through the plate. The working parts are encased in porcelain and the face plate may be given any finish required to match the other hardware trimmings in the building. One of the terminals is shown at s. When one button is pushed in, lever l makes contact with c, c', thus completing the circuit. Snap switches, Fig. 23, are

also made so that they may be mounted flush with the wall. When switches are mounted flush, an iron box should be provided in which to place them. Fig. 24 shows a switch

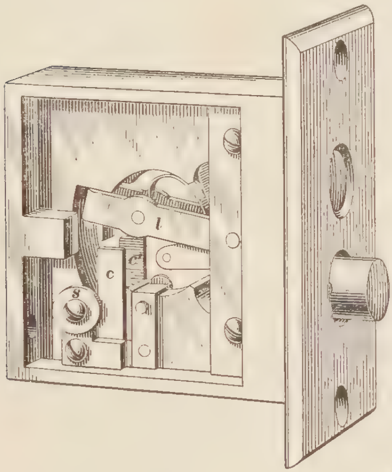


FIG. 22.

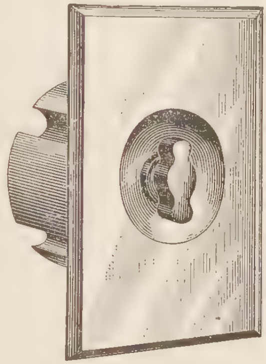


FIG. 23.

box or frame of the kind referred to. A piece of board having an opening large enough to receive the box is nailed between the studding. The box is so mounted that the edge *a* will come flush with the plaster. The box is fastened in position by screws at *b*, *b* and the switch is fastened in the frame by screws *c*, *c*. The use of these frames makes a substantial job and the switch is held securely in place. The switches themselves are not usually installed in the boxes until the fixtures are put up.

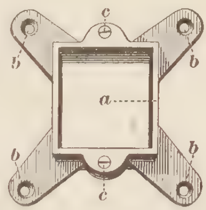


FIG. 24.

In selecting switches, it pays to get good ones. A great deal of trouble is caused by cheap, flimsy switches, in which the springs are always breaking or the parts working loose. A little extra investment put into good switches when the wiring is installed will save a great deal of annoyance and expense afterwards.

FIXTURES.

41. The selection of suitable fixtures and the proper wiring of them are important matters. The wireman should not be satisfied to put up any fixtures that may be furnished. He should examine them and test them himself. The following rules should be followed:

Fixtures—

a. Must, when supported from the gas pipes or any grounded metal work of a building, be insulated from such piping or metal work by means of *approved* insulating joints placed as closely as possible to the ceiling.

It is recommended that the gas outlet pipe be protected above the insulating joint by a non-combustible, non-absorptive insulating tube having a flange at the lower end where it comes in contact with the insulating joint; and that where outlet tubes are used, they be of sufficient length to extend below the insulating joint and that they be so secured that they will not be pushed back when the canopy is put in place. Where iron ceilings are used, care must be taken to see that the canopy is thoroughly and permanently insulated from the ceiling.

b. Must have all burrs, or fins, removed before the conductors are drawn into the fixture.

c. The tendency to condensation within the pipes should be guarded against by sealing the upper end of the fixture.

d. No combination fixture in which the conductors are concealed in a space less than $\frac{1}{4}$ inch between the inside pipe and the outside casing will be approved.

e. Must be tested for contacts between conductors and fixture, for short circuits, and for ground connections before they are connected to their supply conductors.

f. Ceiling blocks for fixtures should be made of insulating material; if not, the wires in passing through the plate must be surrounded with non-combustible, non-absorptive insulating material, such as glass or porcelain.

42. Great care should be taken to see that the sockets are good, and also that they are strong enough to bear the

weight of shades. Faulty sockets are more likely to cause trouble on fixtures than on drop cords, for the socket itself is always grounded on the fixture, and if either wire becomes grounded on the socket shell, it is in consequence grounded on the fixture.

INSULATING JOINTS.

43. The **insulating joint** is the most important electrical fitting used in fixture work. Joints are made for all possible combinations. Fig. 25 shows a very good style; piece *a* screws on to the gas pipe and *b* to the fixture. The parts are separated by insulating material *e*, and the outside of the joint is covered with molded insulation *d*. In connecting fixtures to the wiring, all wires should be kept away from the gas pipe above the joint, but they may be bunched in below the insulating joint after the wires have been spliced, soldered, and taped. It is very important to protect the gas pipe at this point. Insulating joints should be tested before being used. Canopy insulators should be installed wherever there are metal ceilings against which the canopies of fixtures might come. The **canopy** is the brass cup-shaped piece used at the top of fixtures to cover the joint. It is in contact with the fixture; hence, it is important that it be insulated from metal ceilings, or else all the benefits derived from an insulating joint will be lost. Fig. 26 shows a canopy insulator. It is simply an insulating ring placed between the canopy and the ceiling.

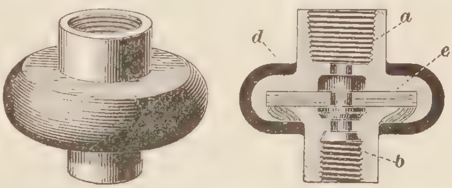


FIG. 25.

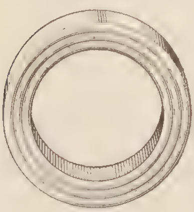


FIG. 26.

44. The student should note the following additional rules relating to insulating joints, fixture wire, etc.

Insulating Joints—

a. Must be made entirely of material that will resist the action of illuminating gases and will not give way or soften under the heat of an ordinary gas flame or leak under a moderate pressure. They shall be so arranged that a deposit of moisture will not destroy the insulating effect and shall have an insulating resistance of at least 250,000 ohms between the gas-pipe attachments, and be sufficiently strong to resist the strain they will be liable to be subjected to in being installed.

b. Insulating joints having soft rubber in their construction will not be approved.

Fixture Wire—

a. Must have a solid rubber insulation, with a slow-burning, tough, outer covering, the whole to be $\frac{1}{32}$ inch in thickness, and show an insulation resistance between conductors and between either conductor and the ground of at least 1 megohm per mile after 1 week's submersion in water at 70° F. and after 3 minutes' electrification with 550 volts.

b. Must not be less in size than No. 18 B. & S.

c. Supply conductors, and especially the splices to fixture wires, must be kept clear of the grounded part of gas pipes, and where shells are used, the latter must be constructed in a manner affording sufficient area to allow this requirement.

d. Must, when fixtures are wired outside, be so secured as not to be cut or abraded by the pressure of the fastenings or motion of the fixture.

e. Under no circumstances shall there be a difference of potential of more than 300 volts between wires contained in or attached to the same fixture.

Decorative Series Lamps.—

Incandescent lamps run in series shall not be used for decorative purposes inside of buildings except by special permission in writing from the Inspection Department having jurisdiction.

45. When old fixtures are to be wired, they must be taken down and supplied with insulating joints. Sockets may be attached to such old gas fixtures by means of spars that fasten to the fixtures at the gas burners. Fig. 27 shows three different styles of these spars.

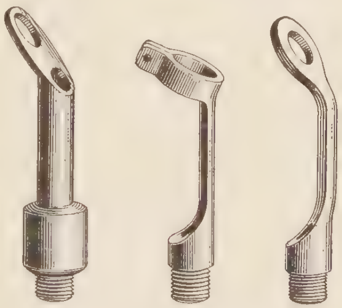


FIG. 27.

LOCATION AND DISTRIBUTION OF LAMPS.

46. The character of the lamps to be used and their location is a matter of much importance that must be determined in each case by the purpose for which the lamps are installed. For signs and decorative work, this purpose is solely to attract attention or to produce ornamentation. In interior lighting, it is to illuminate other objects either close at hand, as with desk lamps, or at a somewhat greater distance. Where illumination is the sole requirement, the lamps should preferably be placed where they cannot be seen, but where they will throw their light upon the object to be illuminated, as on the stage of a theater. In general work, however, it is not possible to place the lamps in this manner, but they should be placed where they will not be too conspicuous. When they must be in view, the lamps should be surrounded by shades that will diffuse the light and take away the glare. Frosted globes are of assistance in many places, but it is better to have the light diffused by a shade. Shadows should be avoided as much as possible.

47. Chandeliers are usually relied on for general illumination. They should be hung high to get the best effects, and should never be as low as the level of the eye of a

person standing. Borders or rows of lights placed on the ceiling near the walls give very good illumination without hurting the eyes. To get the best illumination with the smallest number of lamps, the walls and ceilings should be finished in light colors or in white and kept clean. It is cheaper to retint ceilings than to burn many lamps. This is especially true of stores, where much illumination is a necessity. Walls papered in dark colors and woodwork of dark, rich wood make it almost impossible to brilliantly light a room.

48. It is an exceedingly difficult matter to give any rule for determining the number of lamps required to light a room of given size. Very much depends on the degree of illumination required, on the height at which the lamps are placed, and the color of the walls and ceilings. Experience is about the only reliable guide. The following number of lamps for 100 square feet (Table V) will give an approximate idea as to the number of lights required to produce a given effect, but these values must not be considered as fixed by any means:

TABLE V.

Number of 16-Candlepower Lamps per 100 Square Feet.	Illuminating Effect.
1.25	Dull
1.75	Medium
2.25	Good
3.00	Bright
4.00	Brilliant

If globes are used, the above effects will be reduced.

CONDUIT WIRING.

EARLY CONDUIT SYSTEMS.

49. Not many years ago, before there were uniform rules governing the installation of wires to make them safe, it was a common practice to use for electric lighting wires wound with cotton thread saturated with paraffin. These wires were fastened with wooden cleats nailed against the walls and ceilings. Signal and bell wires are still sometimes put up in this way. The first step in the direction of improvement was limiting the number of incandescent lamps allowed on a given size of wire. The next was the substitution of "weather-proof" or "Underwriters'" wire for the paraffin-covered "office wire." Later came the porcelain cleat, which was not in general use before 1892.

50. The manner of installing wire in concealed work has undergone a similar evolution. At first wires were pulled through holes in the joists and installed without any protection other than their insulating covering; sometimes even two wires were pulled through the same hole, but this was not long tolerated. Progress came along two distinctly different lines: one that of insulating the wire by the use of knobs and tubes, as previously described; the other that of providing a continuous raceway, or **conduit,** for the conductors.

51. One of the first conduit systems and one that came into very extensive use, though it is not now allowed by the Underwriters, was that of the Interior Conduit and Insulating Company. This conduit was made of paper wound in an ingenious manner, so as to form a tube, and coated with tar inside and out. These tubes were installed as a continuous raceway from outlet to outlet. One or two wires, as happened to be most convenient, were pulled into each conduit.

These paper tubes were very brittle, and the system was improved by covering them with a thin shell of sheet brass. Then came the requirement that the conduit should never contain more than one wire. At one time, "brass-covered, interior conduit work" was considered the best possible kind of construction.

52. These paper conduits may still be used to advantage in special places, especially in running wires up and down brick walks, in connection with knob-and-tube work, as an additional protection to wires encased in plaster. It is quite as good as, and in some respects better than, iron pipe for this purpose; and though the Underwriters do not endorse it, most inspectors pass it when thus used. It is also frequently used in place of molding, where wires are run on the surface of walls or in corners, where ordinary molding would be awkward. But it is not tolerated as a conduit proper, because it is not strong enough. Nails can easily be driven through it.

53. Another excellent tube that may still be used in some places, though not approved as a conduit proper, is the flexible **Circular-Loom** tube. This is a woven tube treated with insulating material that makes it hold its shape. It has no metal covering, but is stronger than the brass-covered, interior conduit and more convenient to use. It will be permitted under the present rules only in special cases, as it is not waterproof or nail-proof.

APPROVED CONDUIT SYSTEMS.

54. The conduits now approved by the Underwriters are all iron pipes with more or less insulating lining. They are divided into two classes, *lined* and *unlined*. When unlined conduits are used, an additional braided covering must be placed on the wire. Conduits must comply with the following specifications:

Specifications for Interior Conduits.—

a. Each length of conduit, whether insulated or uninsulated, must have the maker's name or initials stamped in the metal or attached thereto in a satisfactory manner, so that the inspectors can readily see the same.

Metal Conduits with Lining of Insulating Material:

b. The metal covering or pipe must be equal in strength to the ordinary commercial forms of gas pipe of the same size, and its thickness must be not less than that of standard gas pipe, as shown by the following table:

Size. Inches.	Thickness of Wall. Inches.	Size. Inches.	Thickness of Wall. Inches.
$\frac{1}{2}$	.109	$1\frac{1}{4}$	.140
$\frac{5}{8}$	.111	$1\frac{1}{2}$	.145
$\frac{3}{4}$	.113	2	.154
1	.134		

An allowance of $\frac{2}{100}$ inch for variation in manufacturing and loss of thickness by cleaning will be permitted.

c. Must not be seriously affected externally by burning out a wire inside the tube when the iron pipe is connected to one side of the circuit.

d. Must have the insulating lining firmly secured to the pipe.

e. The insulating lining must not crack or break when a length of the conduit is uniformly bent at temperature of 212° F. to an angle of 90°, with a curve having a radius of 15 inches for pipes of 1 inch and less and 15 times the diameter of the pipe for larger pipes.

f. The insulating lining must not soften injuriously at a temperature below 212° F. and must leave water in which it is boiled practically neutral —that is, neither acid nor alkali.

g. The insulating lining must be at least $\frac{1}{32}$ inch in thickness and the materials of which it is composed must be of such a nature as will not have a deteriorating effect on the insulation of the conductor, and be sufficiently tough and tenacious to withstand the abrasion test of drawing long lengths of conductors in and out of same.

h. The insulating lining must not be mechanically weak after 3 days' submersion in water, and

when removed from the pipe entire must not absorb more than 10 per cent. of its weight of water during 100 hours of submersion.

i. All elbows or bends must be so made that the conduit or lining of same will not be injured. The radius of the curve of the inner edge of any elbow not to be less than 3½ inches. Must have not more than the equivalent of 4 quarter-bends from outlet to outlet, the bends at the outlets not being counted.

Unlined Metal Conduits:

j. Plain iron or steel pipes of equal thickness and strengths specified for lined conduits may be used as conduits, provided their interior surfaces are smooth and free from burrs; pipe to be galvanized or the interior surfaces coated or enameled, to prevent oxidization, with some substance that will not soften, so as to become sticky and prevent wire from being withdrawn from the pipe.

k. All elbows or bends must be so made that the conduit will not be injured. The radius of the curve of the inner edge of any elbow not to be less than 3½ inches. Must have not more than the equivalent of 4 quarter-bends from outlet to outlet, the bends at the outlets not being counted.

55. Fig. 28 shows a piece of iron-armored, lined conduit; *a* is the armor about ⅛ inch thick, which is the same as ordinary gas pipe; *b* is the insulating lining, not less than $\frac{1}{32}$ inch thick and adhering to the outer pipe. Conduit, whether lined or unlined, is put up in the same manner as a good job of gas-fitting. Great care should be taken at the joints to see that the pipe is reamed and that the ends come together, so as to form a smooth runway (free from burrs) for the wire. Fig. 29 shows an elbow. In many places the conduit itself may be bent and the use of an elbow with its threaded joints avoided. About as good a way as any to bend conduit is to get a good, stout piece of spruce or hard pine and bore a hole in it a little larger than the conduit. The pipe is then passed through

FIG. 28.

the hole and the bend may be easily worked in. For iron-conduit wiring, the wireman should be provided with a regular outfit of pipe fitter's tools.

56. As previously mentioned, most conduit wiring is now carried out on the single-tube system; i. e., both wires or a twin wire are run in the same conduit. This plan requires less conduit and labor than the double-tube system and is in fact the only allowable arrangement when alternating currents are used. In the case of a large church, supposedly wired for 52 volts, 2 per cent. loss, the contractor ran wires in separate pipes, with the result that when the current was turned on only 13 volts were obtained at the lamps. It is cheaper, as well as better, to use twin or concentric conductors in a single conduit, except for very large cables which are to carry continuous currents.

FIG. 29.

57. Use of Outlet and Junction Boxes.—Since in any conduit system the primary object is to have the wires arranged so that they may be withdrawn, it is necessary, whenever a branch is taken off, to provide a **junction box** of some kind, because it is evident that splices cannot be made at intervening points without interfering with the withdrawal of the wires. Conduit wiring is, therefore, done on the so-called **loop system.** This will be understood by referring to Fig. 30 (*a*) and (*b*); *L*, *L*, *L*, etc. are lamps on one circuit that is to be supplied from a panel board or distributing center located at *A*. In (*a*) the wiring is indicated as it might be done with the ordinary knob-and-tube system, using branches whenever they will reduce the labor

and the amount of wire necessary; (*b*) shows the same lamps wired on the loop system, using outlet boxes *b* and looping out the twin wire at each lamp. No branches are taken off between outlet boxes, and by disconnecting the wires running to the lamps, the main wires may be withdrawn.

The loop system using iron conduits is, of course, very much more expensive than the knob-and-tube system. It is, however, much more permanent in character and is the

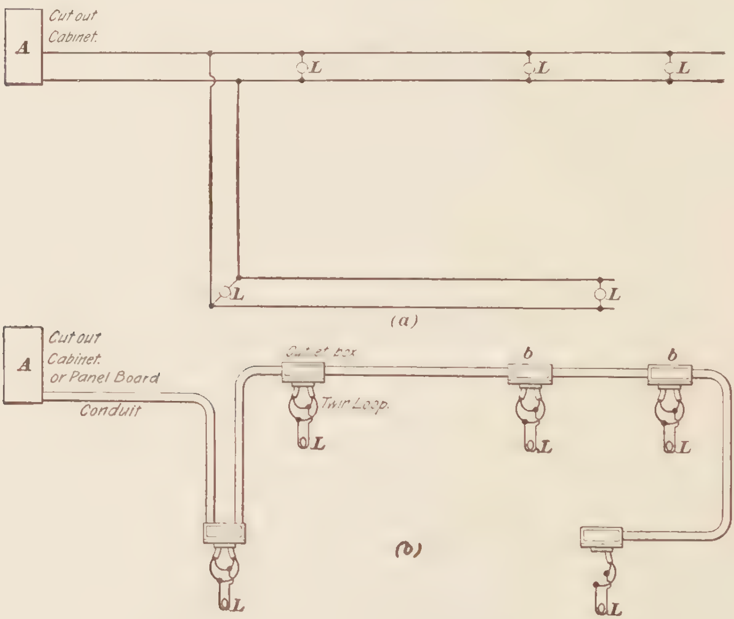


FIG. 30.

only style now used in the best class of buildings. It is used altogether in modern fireproof buildings. The best method of running the conduit, so as to save bends and make the conduit as short as possible, must be left to the judgment of the wireman. In laying out such wiring, he must remember that the two wires are run together and that he cannot make short cuts with single wires as in knob-and-tube work.

58. Conduits less than $\frac{5}{8}$ inch inside diameter are not allowable and an outlet box should be provided at every outlet. When branch lines are taken off, a junction box must be provided. There should not be more than the equivalent of four right-angled bends between junction boxes or there will be difficulty in pulling through the wire. Junction boxes and outlet boxes are manufactured in a large variety of forms to accommodate conduits coming into them from different directions. Fig. 31 (*a*) shows a round

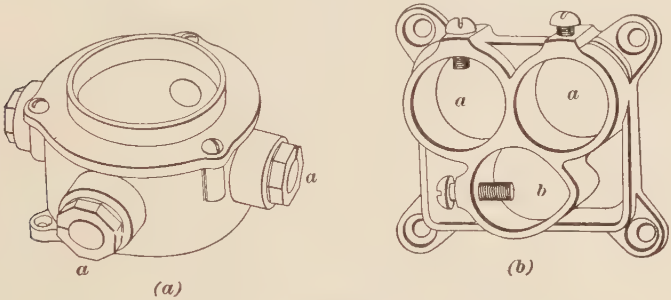


FIG. 31.

junction box. These boxes should be mounted firmly in the wall and be placed so that the surface will come flush with the plastering. The split nuts *a*, *a* hold the conduit in place. Fig. 31 (*b*) shows an **outlet plate.** The conduit is clamped in openings *a* and the gas pipe is clamped in *b*. Very convenient junction and outlet boxes are now made of stamped steel and are arranged so that one or more openings may be made in the side by taking out a small disk. Fig. 32 shows a box of this kind. The conduit enters the box and, projecting through it about $\frac{1}{2}$ inch, is held in place by an insulation cap *a* that screws over the end on the inner side. A check nut *b* screws up against the outside of the box. Fig. 33 shows these fittings more in detail. Boxes of this type may be suited to different locations by simply

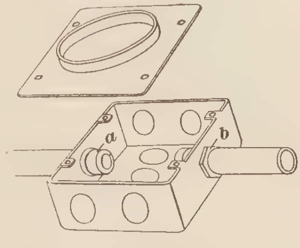


FIG. 32.

knocking out or removing the disks whenever openings are needed. This avoids the necessity of carrying a large

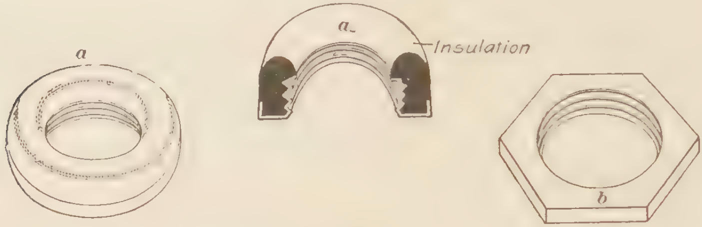


FIG. 33.

number of different boxes in stock. Outlet boxes may be obtained that are provided with special covers to accommodate almost any make of flush switch.

59. Fig. 34 shows a flush switch (with face plate removed) mounted in a switch box suitable for use with iron-armored conduit. Outlet boxes are also made for use with combination fixtures; they are provided with openings for the gas pipe to pass through.

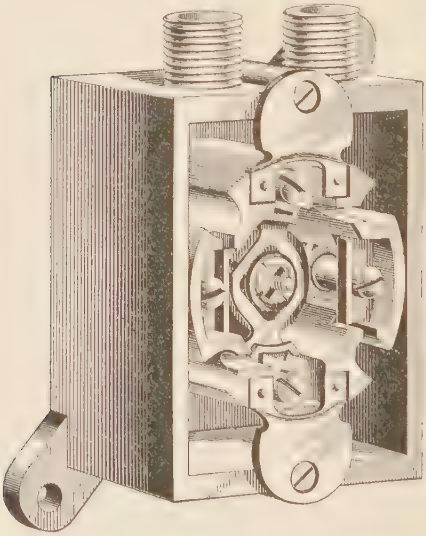


FIG. 34.

When a change in the size of wire is made in a junction box, it is necessary to protect the branch circuits by a cut-out. Special cut-outs are made suitable for mounting in junction boxes. Fig. 35 shows a cut-out suitable for a square box like that shown in Fig. 32. Outlet boxes and cut-outs are also made for places where both gas and electricity are used.

60. Fig. 36 (*a*) and (*b*) shows the method of mounting an outlet box in a fireproof ceiling. By crossing the ells

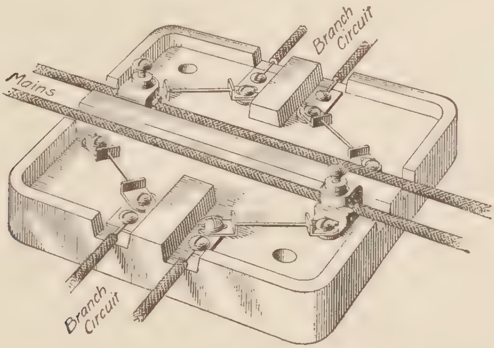


FIG. 35.

as shown at (*b*), the fireproof brickwork does not need to be cut as much as when they are not crossed, as in (*a*). The face of the box should come flush with the plastering. Cement or plaster of Paris may be run in around the box and elbows to hold them securely in place. In work of this kind the conduit is usually run on the upper surface of the fireproof floor as indicated; the strips on which the wood floor is laid usually make sufficient space between the fireproof brick and the wood floor to accommodate the conduit. Where iron conduit is attached to wood beams, it is held by pipe straps in the same way as gas pipe.

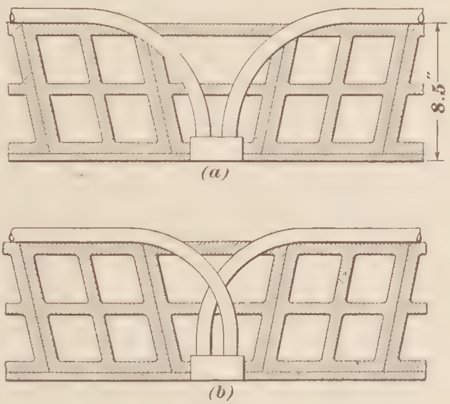


FIG. 36.

61. Underwriters' Rules Relating to Conduit Wire and Installation.—The following rules relating to the wire used for conduit work and the installation of the conduit should be observed:

Conduit Wire—

Must comply with the following specifications:

a. Single wire for lined conduits must comply with the specifications for rubber-covered wire on other low-voltage work. For unlined conduits, it must comply with the same requirements, except that tape may be substituted for braid, and in addition there must be a second, outer, fibrous covering at least $\frac{1}{32}$ inch in thickness and sufficiently tenacious to withstand the abrasion of being drawn through the metal conduit.

b. For twin or duplex wires in lined conduits, each conductor must comply with the specifications for rubber-covered wire on other low-voltage work, except that tape may be substituted for braid and there must be a substantial braid covering over the whole. For unlined conduits, each conductor must comply with the same requirements, except that tape may be substituted for braid and, in addition, must have a braid covering, the whole at least $\frac{1}{32}$ inch in thickness and sufficiently tenacious to withstand the abrasion of being drawn through the metal conduit.

c. For concentric wires, the insulation of the inner conductor must comply with the specifications for rubber-covered wire, except that tape may be substituted for braid, and there must be outside of the outer conductor the same insulation as on the inner, the whole to be covered with a substantial braid, which for unlined conduits must be at least $\frac{1}{32}$ inch in thickness and sufficiently tenacious to withstand the abrasion of being drawn through the metal conduit.

The braid required around each conductor in duplex, twin, and concentric cables is to hold the rubber insulation in place and prevent jamming and flattening.

62. The following rules govern the installation of conduits:

Interior Conduits.—

The object of a tube or conduit is to facilitate the insertion or extraction of the conductors, to protect them from mechanical injury, and, as far as possible, from moisture. Tubes or conduits are to be considered merely as raceways, and are not to be relied on for insulation between wire and wire or between the wire and the ground.

a. No conduit tube having an internal diameter of less than $\frac{5}{8}$ inch shall be used; measurement to be taken inside of metal conduits.

b. Must be continuous from one junction box to another or to fixtures, and the conduit tube must properly enter all fittings.

c. Must be first installed as a complete conduit system, without the conductors.

d. Must be equipped at every outlet with an *approved* outlet box or plate.

e. Metal conduits, where they enter junction boxes and at all other outlets, etc., must be fitted with a capping of *approved* insulating material, fitted so as to protect wire from abrasion.

f. Must have the metal of the conduit permanently and effectually grounded.

Wires in Conduits—

Must not be drawn in until all mechanical work on the building has been as far as possible completed.

Must for alternating-current systems have the two or more wires of a circuit drawn in the same conduit.

It is advised that this be done for direct-current systems also, so that they may be changed to alternating-current systems at any time, induction troubles preventing such a change unless this construction is followed.

There has been much discussion as to what constitutes a permanent and effectual ground in such work. In small installations the ground should be of as great carrying capacity as the conductors within the conduit. In large plants this is not practicable. Where conduits pass from junction box to junction box, they should be well connected, electrically as well as mechanically, to the metal of the boxes, so that no part of the conduit system will be insulated or in poor contact with the rest of the system. On every large

installation, a ground detector should be installed at the main distribution center, so that a ground may be easily located and lifted.

63. While a conduit system is considered merely as a "system of raceways" for the wires, if it is properly installed, all joints firmly made, and an efficient ground provided, it serves the purpose also of an additional protection. No ground can then occur anywhere in the concealed wiring in the building except upon the conduit, and if that is grounded to the earth, it cannot do any damage. If two grounds should occur upon opposite sides of the line, a "dead" short circuit is formed through the walls of the iron pipe. This will blow the fuses on the lines affected, disconnecting them, but doing no other damage. The iron pipe also has the effect of choking back any possible lightning stroke upon the line, thus affording additional protection to the lamps and fixtures.

64. Screw joints between various lengths of pipe and between pipes and junction boxes and cut-out cabinet frames are to be preferred to all other kinds of joints, because they are more secure and afford better electrical contact. To secure them in an entire system, it is necessary to use a few right-hand and left-hand couplings or a few unions. Where unions are used, they should preferably be of brass, because brass gives better contact at the sliding joints than iron. Right-hand and left-hand couplings are also used. In most cases, however, instead of a union or right-hand and left-hand coupling, the thread is cut well back on one piece, the coupling screwed on and afterwards screwed back over the other piece.

But owing to the difficulty of installing screw joints in all places, and because other joints are easier to make and require less expensive fittings (though not so good), many systems have been designed in which other kinds of joints are relied on. Whatever system is used, however, the workman must not shirk the duty of making good pipe connections, which are as important as soldered joints on the wires.

65. Flexible Armored Conduit.—In order to avoid joints and make the conduit cheaper and easier to install, flexible armored conduits have recently been brought forward. Fig. 37 shows a piece of the Greenfield conduit, showing the method of connecting it to a junction box. This conduit is made of steel ribbon wound spirally. It affords a good protection to the wire against mechanical injury, but it is not waterproof. It is, therefore, inferior to the iron conduit for damp places or where the conduit has to be laid in concrete. This conduit may be used for fished work, but is not allowable for a regular conduit system.

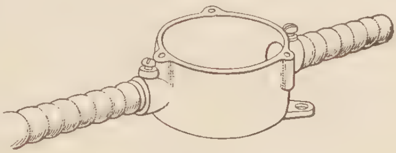


FIG. 37.

66. Economy of Space in Conduit Systems.—In those places where very many circuits are to be run, as, for example, in a partition or along one wall, it is often impossible to find space enough for all the wires and at the same time keep them the distance apart required by the Underwriters. In such cases, they may be run in conduits and placed compactly together side by side.

Where the walls on which the wires are to be concealed are of brick or stone or other masonry, a conduit system offers the only method of concealing the wires that is at once practicable, economical, and permanent. It is the system to adopt for all concealed work in new fireproof buildings and in all other new buildings except those where most of the walls and partitions are of frame covered with lath and plaster, leaving ample space and easy work for knob-and-tube construction.

In large buildings where there are to be many electric conduits, architects usually provide channels in the brickwork in which the conduits can be placed, so as to bring them behind the surface of the brick without having to cut the brick with a chisel after it is in place, which is a laborious and objectionable method.

67. Drawing Wires in Conduits.—When the wires are to be drawn into conduits, it is a good plan to blow soapstone through first, as it makes the wire slide through easier

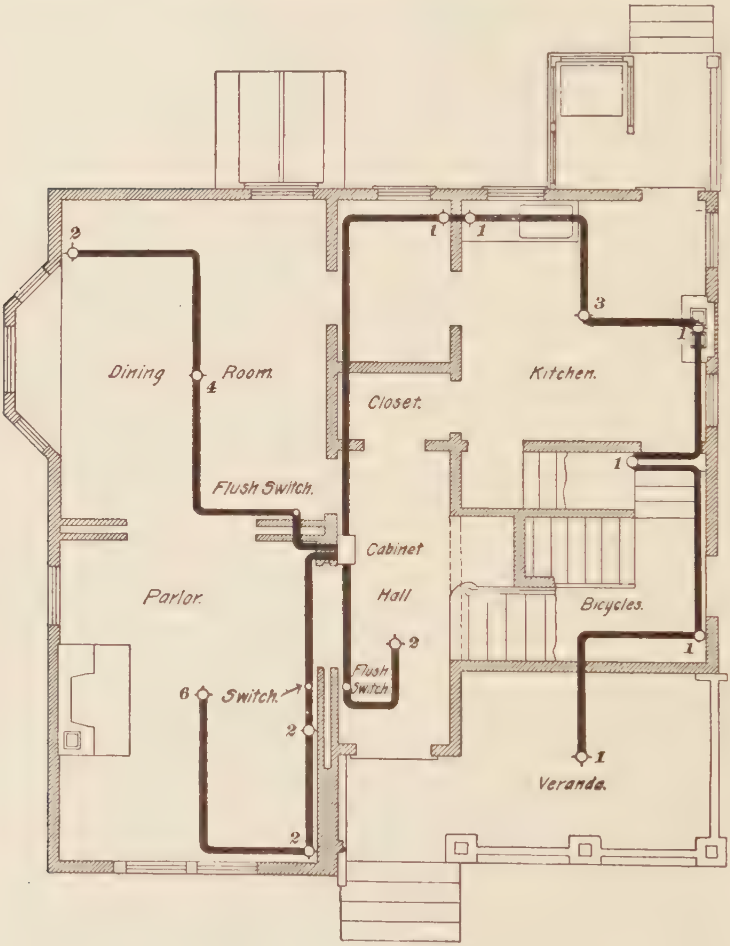


FIG. 38.

and take the ells better. A "snake" is first run through the tube and the wire pulled through by means of it. The *snake* usually consists of a steel ribbon about $\frac{1}{8}$ inch wide

with a ball about $\frac{1}{4}$ inch diameter on the end. If the conduit has many turns, it is advisable to use a coiled spiral spring about $\frac{1}{4}$ inch diameter and 6 or 8 inches long with a ball on one end and the other end fastened securely to the steel ribbon. The end with the piece of spring is pushed in first and the spring passes around the turns easily.

68. Fig. 38 shows one floor of a dwelling house wired with conduits. The numbers on the various outlets indicate the number of lamps supplied. The wiring is carried out on the loop system, and it will be noticed that no branches are taken off between outlets. Four circuits are used in order that there may not be more than ten lamps on any one circuit.

WOODEN MOLDINGS.

69. Wooden moldings are used to a great extent in running wires over woodwork, on walls, door and window frames, and other places where they cannot otherwise be well concealed. Moldings put up on ceilings or walls should be arranged symmetrically, so as to disguise their purpose, or at least not disfigure a room, even though it may be necessary to put up blank or empty molding for this purpose. Work of this kind is confined almost exclusively to old buildings. The following rules relate to these moldings:

Wooden Moldings—

a. Must have both outside and inside at least two coats of waterproof paint or be impregnated with a moisture repellent.

b. Must be made of two pieces, a backing and capping so constructed as to thoroughly encase the wire and provide a $\frac{1}{2}$-inch tongue between the conductors and a solid backing that, under the grooves, shall not be less than $\frac{3}{8}$ inch in thickness, and must afford suitable protection from abrasion.

It is recommended that only hardwood molding be used.

Wires—

For molding work:

Must have *approved* rubber-insulating covering.

Must never be placed in molding in concealed or damp places or where the difference of potential between any two wires in the same molding is over 300 volts.

70. Irresponsible parties sometimes run weather-proof wire in moldings. This practice is dangerous, for in molding work there is practically no insulation except that on the wire, if the molding becomes damp; while in cleat and tube work there is an air space, and in conduit work an iron pipe, as an additional protection. Moreover, a wire with an air space or an iron jacket around it cannot do much damage even if it does become very hot; but a wire embedded in wood if overloaded excessively will char and possibly set fire to the wood, because the heat cannot easily be dissipated. Dampness is the greatest enemy of molding work.

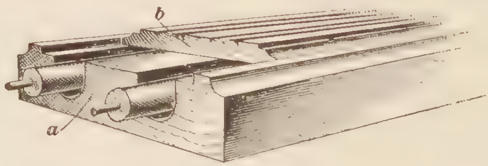


FIG. 39.

However, where hardwood moldings and rubber-covered wires of sufficient size are used in places always dry, this kind of work is quite safe and is very much in vogue at the present day. Moldings are especially convenient in running border lights around the walls of rooms, where lamps are placed a foot or so apart, and in wiring show windows for temporary displays, and other work of a semi-permanent nature. Moldings are made in a variety of styles, some of which are ornamental and nicely finished to match the trimmings of the rooms in which they are used. Fig. 39 shows a typical two-wire molding that conforms to the Underwriters' requirements, since it has the backing *a* and capping *b*.

TESTS.

71. After a job of wiring has been completed, **tests** should be made to see if all connections are correct and also if there are any grounds or crosses between the wires. All circuits should be tested before fixtures of any kind are put up, and each fixture should be tested carefully before it is put in place. Fixtures when received from the factory are not usually wired, and connecting the sockets, etc. must be done before they are put in place. If this is not carefully done, the fixture wire is apt to become grounded; hence, the

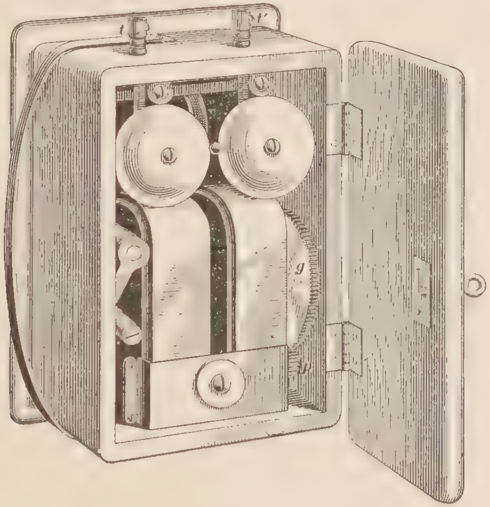


FIG. 40.

necessity of testing out fixtures before they are put into position. For most of this testing a magneto-bell is used. This is a small hand, electric generator connected with a bell similar to the call bell on a telephone. Fig. 40 shows a portable magneto made for testing work; t, t' are the terminals to which wires are attached in order to test any circuit. When a circuit is established between t, t', the bell rings. These instruments are made of various capacities designed to ring the bell through resistances of 5,000 to 10,000 ohms, or more.

72. Each branch circuit should be tested individually with the magneto by connecting it to the terminals of the circuit at the panel board or cut-out. The wires at all the outlets should be separated and the circuit rung up. If no ring is obtained, it shows that there is no cross between the wires. The wires coming out of each outlet should then be touched together in turn and also their corresponding switch outlets, if there are any, to see if the connections to the outlets are all right. After each outlet is rung up, its wires should be left separated. Each side of the circuit should then be tested for grounds. If it is a conduit system, one terminal of the magneto should be connected to the sheathing and the other to each side of the circuit in turn. If no ring is obtained on either side, it shows that the wire is clear of grounds. If a ring is obtained, the ends should be carefully examined, and if necessary the wire must be drawn out and examined. In knob-and-tube work the method of testing is practically the same, only in testing for grounds one side of the magneto may be connected to a gas or water pipe. Each fixture should be subjected to similar tests, and after all the fixtures are in place, the system as a whole should be tested.

73. Underwriters' Tests.—An insurance inspector usually tests each branch line with a magneto for continuity, short circuits, and grounds. He then usually counts up the number of lamps on each circuit and notes the sizes of wire used to see that no wire is overloaded when all the lamps are on. Concealed work must be inspected before the lath and plaster are put on, otherwise it will not be passed without special investigation; this means tearing up floors and walls, which is expensive, to say the least.

In most installations, where the inspector has no reason to suspect that any faulty material has been used, he is able to satisfy himself by these tests and by examining the work with his eye; in fact, in many cases an ocular inspection is the only inspection made by the authorities, if they are satisfied that the contractor is honest and has made the other necessary tests.

74. Where more particular attention is given to a piece of work or where it is desired to learn whether an old installation or one not properly inspected at the time the work was done is up to the standard of safety, the insulation resistance is measured.

Insulation Resistance.—

The wiring in any building must test free from grounds; i. e., the complete installation must have an insulation between two separate conductors and also between all conductors and the ground (not including attachments, sockets, receptacles, etc.) of not less than the following:

Up to 5 amperes	4,000,000 ohms.
Up to 10 amperes	2,000,000 ohms.
Up to 25 amperes	800,000 ohms.
Up to 50 amperes	400,000 ohms.
Up to 100 amperes	200,000 ohms.
Up to 200 amperes	100,000 ohms.
Up to 400 amperes	25,000 ohms.
Up to 800 amperes	25,000 ohms.
Up to 1,600 amperes	12,500 ohms.

All cut-outs and safety devices should be in place when the above test is made.

Where lamp sockets, receptacles, and electroliers, etc. are connected, one-half of the above will be required.

Where lamps or other devices are suspected of taking more current than they should or where the load on any line is, for any reason, in doubt, the current should be measured with an ammeter.

MEASUREMENT OF DROP IN VOLTS.

75. If the current can be turned on in order to make a test of the drop in voltage, the best way is to use a voltmeter and determine the actual drop on each line at full load. With an ordinary voltmeter, the best method is to have two pairs of test cords and plugs connected to a double-pole double-throw switch. One pair of test cords should run to the distribution center; the other should run to the fixture to which the drop is to be determined. The switch should be so connected to the voltmeter that a reading of

the voltage at the end of one pair of cords can be taken one instant and that at the end of the other pair of cords the next. The difference is the drop in volts on that line. All of the lamps should be turned on while the measurements are being taken, and several sets of readings should be made, because currents supplied from central stations suffer variations in voltage.

MARINE WORK.

76. Wiring on board ships is subjected to some special conditions and therefore requires special treatment. The first important condition not usually met with on land is the motion of the ship, which makes it necessary to avoid all forms of construction where chafing or breaking might take place. The second important peculiarity is the constant dampness of the atmosphere. For these and other reasons a separate code has been prepared for marine work, from which the following rules are selected. They embody the chief points in which marine work differs from other work.

Wires—

a. Must be supported in approved molding or conduit except at switchboards and portables.

Special permission may be given for deviation from this rule in dynamo rooms.

b. Must have no single wire larger than No. 12 B. & S. Wires to be stranded when greater carrying capacity is required. No single solid wire smaller than No. 14 B. & S. except in fixture wiring to be used.

Stranded wires must be soldered before being fastened under clamps or binding screws, and when they have a conductivity greater than No. 10 B. & S. copper wire, they must be soldered into lugs.

c. Splices or taps in conductors must be avoided as far as possible. Where it is necessary to make them, they must be so spliced or joined as to be both mechanically and electrically secure without solder. They must then be soldered, to insure preservation,

covered with an insulating compound equal to the insulation of the wire, and further protected by a waterproof tape. The joint must then be coated or painted with a waterproof compound.

Wires for Molding Work—

a. Must have an *approved* insulating covering.

The insulation for conductors, to be approved, must be at least $\frac{3}{32}$ inch in thickness and covered with a substantial waterproof and flame-proof braid.

The physical characteristics shall not be affected by any change in temperature up to 200° F. After 2 weeks' submersion in salt water at 70° F., it must show an insulation resistance of 1 megohm per mile after 3 minutes' electrification with 550 volts.

b. Must have when passing through water-tight bulkheads and through all decks a metallic stuffing tube lined with hard rubber. In case of deck tubes, they shall be boxed near deck to prevent mechanical injury.

c. Must be bushed with hard-rubber tubing $\frac{1}{8}$ inch in thickness when passing through beams and non-water-tight bulkheads.

Wires for Conduit Work—

a. Must have an *approved* insulating covering.

The insulation for conductors for use in lined conduits, to be approved, must be at least $\frac{3}{32}$ inch in thickness and be covered with a substantial waterproof and flame-proof braid. The physical characteristics shall not be affected by any change in temperature up to 200° F.

After 2 weeks' submersion in salt water at 70° F., it must show an insulation resistance of 1 megohm per mile after 3 minutes' electrification with 500 volts.

For unlined metal conduits, conductors must conform to the specifications given for lined conduits, and in addition have a second, outer, fibrous covering at least $\frac{1}{32}$ inch in thickness and sufficiently tenacious to withstand the abrasion of being drawn through the metal conduit.

b. Must not be drawn in until the mechanical work on the conduit is completed and the same is in place.

c. When run through coal bunkers, boiler rooms, and where they are exposed to severe mechanical injury, must be encased in approved conduit.

TABLE VI.

Table of Capacity of Wires for Marine Work.

B. & S. G.	Area Actual C. M.	Number of Strands.	Size of Strands B. & S. G.	Amperes.
19	1,288			
18	1,624			3
17	2,048			
16	2,583			6
15	3,257			
14	4,107			12
12	6,530			17
	9,016	7	19	21
	11,368	7	18	25
	14,336	7	17	30
	18,081	7	16	35
	22,799	7	15	40
	30,856	19	18	50
	38,912	19	17	60
	49,077	19	16	70
	60,088	37	18	85
	75,776	37	17	100
	99,064	61	18	120
	124,928	61	17	145
	157,563	61	16	170
	198,677	61	15	200
	250,527	61	14	235
	296,387	91	15	270
	373,737	91	14	320
	413,639	127	15	340

Portable Conductors—

Must be made of two stranded conductors, each having a carrying capacity equivalent to not less than No. 14 B. & S. wire, and each covered with an approved insulation and covering.

Where not exposed to moisture or severe mechanical injury, each stranded conductor must have a solid insulation at least $\frac{1}{32}$ inch in thickness and must show an insulation resistance between conductors and between either conductor and the ground of at least 1 megohm per mile after 1 week's submersion in water at 70° F. and after 3 minutes' electrification with 500 volts, and be protected by a slow-burning, tough-braided, outer covering.

Where exposed to moisture and mechanical injury—as for use on decks, holds, and firerooms—each stranded conductor shall have a solid insulation, to be approved, of at least $\frac{1}{32}$ inch in thickness and be protected by a tough braid. The two conductors shall then be stranded together, using a jute filling. The whole shall then be covered with a layer of flax, either woven or braided, at least $\frac{1}{32}$ inch in thickness,

and treated with a non-inflammable, waterproof compound. After 1 week's submersion in water at 70° F., at 550 volts, and a 3 minutes' electrification, must show an insulation between the two conductors or between either conductor and the ground of 1 megohm per mile.

Wooden Moldings—

a. Must be made of well-seasoned lumber and be treated inside and out with at least two coats of white lead or shellac.

b. Must be made of two pieces, a backing and a capping, so constructed as to thoroughly encase the wire and provide a $\frac{1}{2}$-inch tongue between the conductors and a solid backing that, under the grooves, shall not be less than $\frac{3}{8}$ inch in thickness.

c. Where molding is run over rivets, beams, etc., a backing strip must first be put up and the molding secured to this.

d. Capping must be secured by brass screws.

Cut-Outs.—

a. In places such as upper decks, holds, cargo spaces, and firerooms, a water-tight and fireproof cut-out may be used, connecting directly to mains when such cut-out supplies circuits requiring not more than 660 watts energy.

b. When placed anywhere except on switchboards and certain places, as cargo spaces, holds, firerooms, etc., where it is impossible to run from center of distribution, they shall be in a cabinet lined with fire-resisting material.

c. Except for motors, searchlights, and diving lamps, shall be so placed that no group of lamps requiring a current of more than 6 amperes shall ultimately be dependent on one cut-out.

A single-pole covered cut-out may be placed in the molding when same contains conductor supplying circuits requiring not more than 220 watts energy.

Fixtures—

a. Shall be mounted on blocks made from well-seasoned lumber treated with two coats of white lead or shellac.

b. Where exposed to dampness, the lamp must be surrounded by a vapor-proof globe.

c. Where exposed to mechanical injury, the lamp must be surrounded by a globe protected by a stout wire guard.

WIRING ESTIMATES.

77. It is difficult to lay down any reliable rules to be used in estimating the cost of a proposed wiring job. As when estimating in other lines of work, experience must largely be relied on. The prices of labor and material vary so widely in different sections of the country that any general rules might lead to very inaccurate results. Moreover, these prices are always fluctuating. One frequently sees statements to the effect that certain kinds of wiring can be done for so much per lamp or so much per outlet, but it is evident that while such figures might be fairly correct so far as the average of a large number of installations is concerned, they might be far from correct when applied to individual cases.

78. The only way in which to obtain a fairly close estimate of the cost of a given installation is to prepare plans and lay out the circuits, marking the size of the wire and the capacity of the various switches and cut-outs required. By laying out these plans, the amount of wire, conduit, and other material required may be arrived at quite closely. The number of switches, cut-outs, etc. can be counted up and their cost estimated. In measuring the length of the circuits, do not forget to take into account the wire and material necessary for running up and down walls to switches or outlets. Margin should be allowed for such material as tape, solder, etc. The labor item will depend largely on whether the building to be wired is an old one or one in the process of construction, also on the style of wiring used, so that the labor item can only be determined from a careful inspection of the premises to be wired and experience on work of a similar class. An ordinary two-story dwelling house wired on the concealed knob-and-tube system will require about 6 days' labor of a man and helper. This is for a medium sized house. Some small houses will require less than this. Old houses require a much larger expenditure of labor, because there is liable to be considerable molding work to be done.

79. As stated before, it is unsafe to assume a certain cost per outlet in figuring on a job of wiring unless one has been doing considerable work of a certain class. As a rough guide, however, it may be stated that ordinary dwellings wired on the concealed knob-and-tube plan will cost from $2.00 to $3.00 per outlet. This, of course, does not include the fixtures, but should cover the cost of snap switches and porcelain cut-outs. Ordinary exposed wiring can usually be run for $1.00 to $1.75 per drop, including rosettes, cord, and sockets, though, of course, very much depends on how closely the lights are grouped. It is evident that if the lamps are scattered very much, the cost of wire, porcelain fittings, and labor will be comparatively high, and this will increase the cost per drop. Wiring with iron-armored conduit is expensive, but it is substantial. It is difficult to give any figures as to the cost per outlet. For small installations, it will probably cost from $5.00 to $6.00 per outlet; in large installations, the cost will be somewhat less. The student must remember that these figures are approximate only. The cost in different localities might vary widely from the above, and the only way to make a fairly close estimate is to lay out the circuits, make a list of the material needed, and estimate their cost and the probable labor required.

INTERIOR WIRING.

(PART 3.)

COMBINING SEVERAL WIRING SYSTEMS.

STORE LIGHTING.

1. A large electric-light installation generally requires many kinds of wiring, and there are usually special conditions that determine what kind of work is to be done in each locality. As an example, we will take the wiring system of a certain department store as it was actually put in.

After a careful study of the conditions existing, the managers of the store concluded that enclosed-arc lamps were best suited for the general illumination of their stores, and that incandescent lamps should be installed for use at desks, in closets and warerooms, and occasionally in show windows. Accordingly, the premises were wired for 250 enclosed-arc lamps and 500 incandescent lamps at 110 volts.

Separate feeder wires were run to each of the ten departments. The dynamos were installed in the engine room in the subbasement, one machine capable of supplying current for one-third of the lamps to be used when the load was light, and one generator capable of operating two-thirds of the lamps, and some small motors. When the entire load was on, the two generators operated in multiple.

For notice of copyright, see page immediately following the title page.

2. In order that light could be secured in case of a breakdown of the plant, service wires from the Edison three-wire system were brought into the basement and connected to the switchboard in such a manner that this current could be used in an emergency. The double-throw switches and connections necessary to change over from the two-wire to the

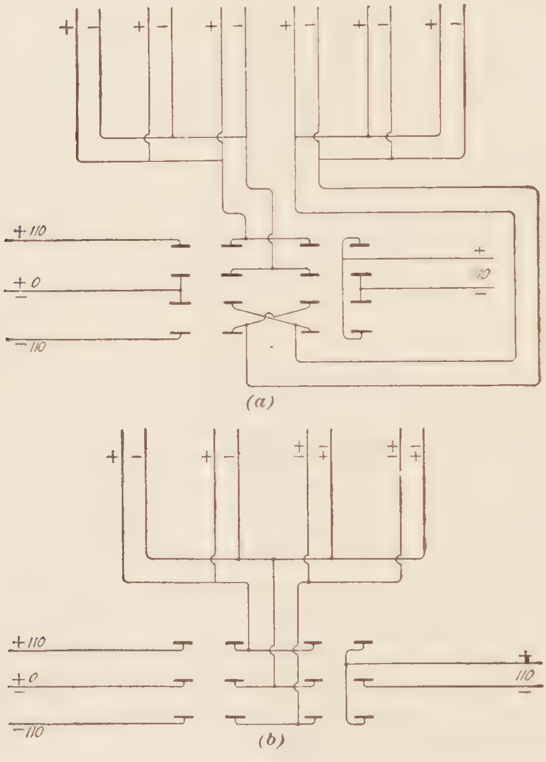


FIG. 1.

three-wire system, where arc lamps are used, are shown in diagram in Fig. 1 (*a*). A special four-pole double-throw switch was installed. If there were no arc lamps requiring that the direction of the current must be constant, one three-pole double-throw switch, connected as in Fig. 1 (*b*), would have been sufficient. The use of the three-wire

system in this case involved no saving in the lines, as that system extended only to the main switchboard, beyond which the two-wire system was used.

3. The feeder cables were run from the engine room to the centers of distribution in each of the various departments, in iron-armored conduits, one cable to a conduit. Cables and not wires were used, because heavy, solid conductors cannot be drawn into conduits with bends in them. These conduits were put together with screw couplings, with corner boxes of special design at each elbow, as the cables were very heavy. In the basement the conduits were all connected together by locknuts and a bus-bar, which was grounded to the water main back of the main valve on the automatic-sprinkler system by an iron rod, which was inserted in the water pipe like a tap. This afforded an excellent ground.

4. Cut-out cabinets were installed in each department. When in conspicuous places, they contained marble tablets upon which were mounted lugs to receive fuses. Enclosed fuse links were used. A switch was provided on the tablet for each circuit. All connecting wiring was done on the back of the board and was thus concealed. The tablets were mounted in hardwood cabinets with plate-glass doors that opened by sliding downwards like a window sash. In less conspicuous places, the cabinets were provided with hinged wooden doors, were lined with asbestos, and provided with porcelain link fuse cut-outs of the open-fuse type. For each enclosed-arc lamp a separate branch line was run from the nearest cut-out cabinet. Large departments were provided with several cut-out cabinets connected to the same pair of feeders.

5. The branch lines were run in various ways; some of them were run in pipes, some were run in molding, and some were run open. Where they were placed in pipes, twin conductors were used and the lamps were hung from the pipe ends by means of an insulating joint. All the branch pipes were connected together and to the feeder

pipes at the cut-out cabinet in the same way as those pipes were connected together in the basement.

6. A drop of 2 volts was allowed in the mains and a drop of 1 volt in the distributing wires for incandescent lamps. The distributing wires for the arc lamps were all of No. 14 wire, and the resistances at the lamps were adjusted so as to secure 80 volts at the arc. From a distribution closet in one of the busiest departments, twin conductors of No. 14 wires were run to the generator switchboard, in an iron pipe, and connected to a voltmeter on the switchboard. The terminals of these pressure wires in the closet were connected, with proper cut-out protection, to the terminals of the feeders. The dynamo tender was, therefore, able from the indications of the voltmeter to regulate his machines so as to maintain a constant potential of 110 volts at the cabinets.

7. The show windows were lighted by enclosed-arc lamps hung in the space above the goods displayed, but out of sight from the street. Only the outer globes projected below the dust-proof casing surrounding the window space. Thus, brilliant illumination was secured with very little glare and with great economy. The lamps were so arranged that they could be lifted out of the globes whenever it was necessary to trim them; but the globes were never removed, being cleaned while in place. This arrangement proved very effective and convenient. Additional circuits were run to various points for connecting incandescent lamps and special apparatus for holiday displays.

THEATER WIRING.

8. The wiring of theaters and entertainment halls presents some peculiar features. All the lamps in the theater must be controlled from one point, usually on the right wing of the stage. The gas lighting is also controlled from the same point. Most of the lights on the stage are arranged in borders, or long rows, which contain several circuits of

lamps of various colors, and are also usually provided with dimmers. Therefore, the stage switchboard of a large theater is quite a complicated affair compared with the distribution closets used in ordinary work.

In cases where there are a large number of borders of incandescent lamps, it is inconvenient to divide them into circuits of only 660 watts, and permission can usually be obtained from the Underwriters to place more lamps on such circuits if special care is taken.

9. Stage dimmers are of two kinds, *resistance boxes* and *reactive coils.* The latter are more economical, but can be used with alternating currents only. Care must be taken to locate resistance boxes where they can be kept cool by the circulation of fresh air. **Equalizers** are used to regulate voltages within small limits when large currents are used, as, for example, to correct unbalancing of the three-wire system. They are made of small resistance and large carrying capacity. The following Underwriters' rules relate to the installation of these appliances:

Resistance Boxes and Equalizers—

Must be equipped with metal or with other non-combustible frames.

The word "frame" in this section relates to the entire case and surroundings of the rheostat, and not alone to the upholding supports.

Reactive Coils.—

Reactive coils must be made of non-combustible material, mounted on non-combustible bases, and treated, in general, like sources of heat.

Most of the dimmers in common use consist of a resistance split up into a number of sections, so that the amount of resistance in series with the lamps may be varied. They are made in a number of different forms, some of them being arranged so that their operating handles interlock so that they may be operated singly or together in any desired combination. Dimmers are, of course, connected *in series* with the circuits that they are intended to control.

WIRING FOR SPECIAL PURPOSES.

10. While in most work of a permanent character the closet system of distribution, with very slight drop in the branch lines, is the proper system to adopt, there are special conditions that sometimes make it desirable to install wires for a very low price, for temporary or occasional use. In such installations, the efficiency is of comparatively little importance, but the proper regulation and uniform voltage at the lamps are as important as in permanent work.

11. Let us take a case, such as the installation of a thousand 8-candlepower lamps for decorative purposes around the cornices of a building at a fair, where the wires will be up for a few days or weeks only. All the lamps are to be

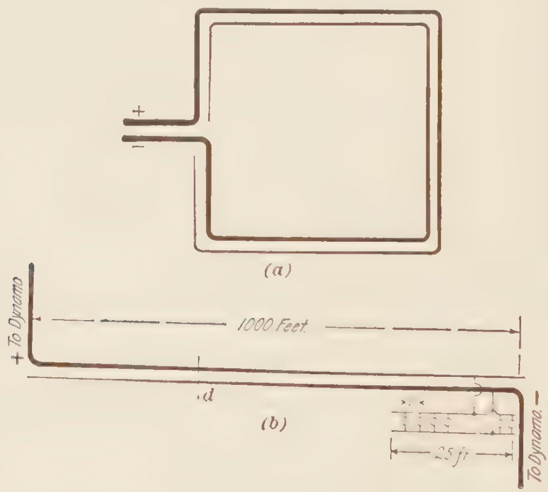


FIG. 2.

burned at the same time. In such a case, it may be economical to allow as much as 12.5 per cent. drop on the lines and use 100-volt lamps on 112.5-volt service. We will run but one pair of feeder lines around the building, a distance of 1,000 feet. We desire to have the drop on these lines such that we will have 100 volts at any point between

them and 112.5 volts at the terminals. This can only be accomplished by running the lines in opposite directions and having them change in size often enough to secure practically uniform drop per foot. Fig. 2 (*a*) illustrates such an arrangement, and (*b*) shows the same thing drawn in a straight line instead of a square. This is sometimes called the *anti-parallel* method of feeding.

12. There will be a lamp for every foot. There will be required 40 branches of No. 14 wire, with 25 lamps on each branch, as shown in Fig. 2 (*b*). Weather-proof wall receptacles will be used. The total length of wire in the mains is 2,000 feet. The length of wire to any given branch is 1,000 feet; hence, the rate of drop must be 12.5 volts per 1,000 feet. On account of the method of feeding from each end, it is easily seen in Fig. 2 (*b*) that the length of wire through which the current flows to any point *d* must be 1,000 feet. The currents that various wires will carry with a drop of 12.5 volts are as follows:

Size of Wire.	*Volts Drop.*		*Resistance per 1,000 Feet.*		*Amperes.*
No. 14	12.5	÷	2.521	=	4.96
No. 12	12.5	÷	1.586	=	7.88
No. 10	12.5	÷	.997	=	12.5
No. 8	12.5	÷	.627	=	19.9
No. 6	12.5	÷	.394	=	31.7
No. 5	12.5	÷	.313	=	39.9
No. 4	12.5	÷	.248	=	50.4

The amperes for larger wires can be be found by consulting the tables in *Interior Wiring*, Part 2.

Since the lamps are to be 8 candlepower, there will be about 1 ampere for every 4 lamps, and consequently for every 4 feet of line (2 wires). In making up a conductor to have nearly uniform drop, it will be necessary for us to compromise for all points that do not exactly correspond with the above-calculated current values. For instance, if we join No. 12 wire to No. 14 wire, it must be at a point where there is between 4.96 and 7.88 amperes. If we select

lengths of wire that will bring this joint half way between the points where the wires exactly correspond, it will be near enough. We then will have results as given by the following table:

Size of Wire.	Amperes Giving 12.5 Volts per 1,000 Feet.	Corresponding Distance from End of Line.	Distance of End of Wire from End of Line.	Length of Wire to be Used.
14	4.96	20	26	26
12	7.88	32	41	15
10	12.5	50	65	24
8	19.9	80	104	39
6	31.7	127	144	40
5	39.9	160	181	37
4	50.4	202	228	47
3	63.5	254	290	62
2	80.1	320	362	72
1	100.8	403	457	95
0	127.5	510	576	119
00	160.3	641	724	148
000	201.6	806	915	191
0000	255.1	1,020	1,000	85

In the above table the second column is obtained by dividing the volts drop (12.5) by the resistance per 1,000 feet of the various sizes of wire. The third column is found by taking the approximate value of the current multiplied by 4 because there is 1 ampere for every 4 feet of cornice. The fourth column is obtained by taking one-half the difference between the succeeding quantities in column 3 and adding this difference to the quantity in column 3. For example, at a point 20 feet from the end the current is 4.96 amperes and at a point 32 feet from the end it is 7.88 amperes. As stated above, we will select lengths of wire that will bring the joints between the different sizes of wire midway between the points where the wires correspond.

Hence, in the first case if we have a current of 7.88 amperes 32 feet from the end and a current of 4.96 amperes 20 feet from the end, the joint will be $20 + \frac{32 - 20}{2} = 26$ feet from the end and 26 feet of No. 14 wire will be required. Also in the case of the No. 8 and No. 6 wires, we have 19.9 amperes 80 feet from the end and 31.7 amperes 127 feet from the end; hence, the joint between the two sizes will be $80 + \frac{127 - 80}{2}$ $= 103.5$ feet from the end. In the table, the nearest even feet are given, so that this is taken as 104. In the case of the 0000 wire, the distance from the end of the line corresponding to a drop of 12.5 volts works out 1,022 feet, though, of course, there would not be quite as large a current as 255.1 amperes because the line cannot be longer than 1,000 feet. This quantity is, however, used in determining the distance (915 feet) of the end of the 000 wire from the end of the line. The distance of the end of the 0000 wire must, of course, be 1,000 feet because the cornice is 1,000 feet long. The lengths in column 5 are obtained by subtracting the successive values of column 4, for example $65 - 41 = 24$, $104 - 65 = 39$, etc.

13. Cut-outs of the following amperes capacity would have to be installed:

15 amperes, to protect Nos. 14, 12, and 10.
65 amperes, to protect Nos. 8, 6, 5, 4, and 3.
130 amperes, to protect Nos. 2, 1, and 0.
160 amperes, to protect No. 00.
250 amperes, to protect Nos. 000 and 0000.

This statement assumes that weather-proof wire is to be used. Fig. 3 is a diagram of a portion of the wiring in place, showing the connections of cut-outs.

14. Another method of wiring for temporary work is to put up wires on the feeder system just large enough to carry the current, and then calculate the drop and install lamps of the required voltage. This is a simple and very

cheap method. In the case of the border lamps just considered, if wired in this way, we could use eight pairs of feeders of No. 10 wire, with 125 lamps per feeder. If we

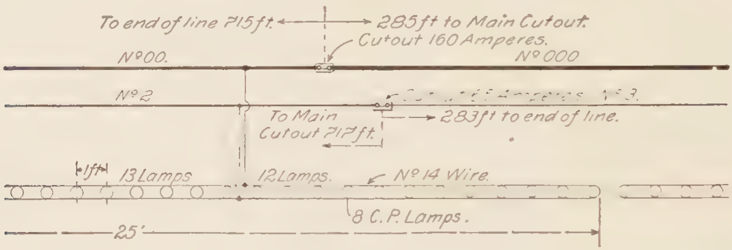


FIG. 3.

arrange the feeders as shown in Fig. 4, the lengths of these feeder lines and the drop on each would then be roughly as follows, if each lamp required $\frac{1}{4}$ ampere. Current in each

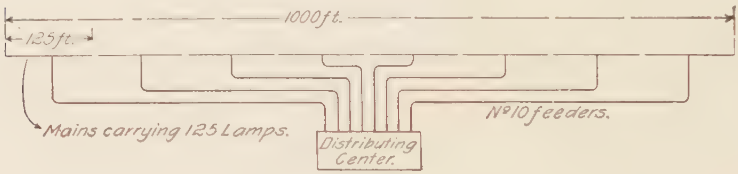


FIG. 4.

feeder is $\frac{125}{4}$ amperes, and No. 10 wire has a resistance of about 1 ohm per thousand feet. The approximate length of the feeders will be as given below:

2 lines 425 feet (2 wires) long, 26.6 volts drop.
2 lines 300 feet (2 wires) long, 18.8 volts drop.
2 lines 175 feet (2 wires) long, 10.9 volts drop.
2 lines 50 feet (2 wires) long, 3.1 volts drop.

The drop in the first case $= \frac{125}{4} \times .425 \times 2 = 26.6$. The others are found in a similar manner. In the distribution, about 1 volt would be lost. Consequently, if 125 volts are supplied, the lamps should have voltages of 97, 105, 113, and 121 if each lamp requires $\frac{1}{4}$ ampere.

15. There are many other methods or plans by which such a building as this could be wired for a large drop and

still be furnished with uniform and steady light. The suggestions here given are merely to set the student thinking about the matter of saving material. By making every installation a matter of special study, until he has thoroughly mastered every detail of the business, he will discover many ways of economizing labor and material that cannot be brought to his attention in any other way. Before using any unusual method, however, he should make certain that there is no objection on the part of the Underwriters or of the Fire Department to what he proposes to do.

HIGH-POTENTIAL SYSTEMS.

16. The foregoing rules have applied to systems using 550 volts or less. For pressures over 550 volts, the following rules apply:

HIGH-POTENTIAL SYSTEMS.

550 to 3,500 Volts.

Any circuit attached to any machine or combination of machines which develops a difference of potential between any two wires of over 550 volts and less than 3,500 volts shall be considered as a high-potential circuit and as coming under that class, unless an approved transforming device is used which cuts the difference of potential down to 550 volts or less.

Wires—

a. Must have an *approved* rubber-insulating covering.

The thickness of the insulating walls must not be less than those given in the following table for B. & S. gauge sizes:

From 14 to 1, inclusive, $\frac{3}{32}''$.
From 0 to 500,000 C. M., $\frac{3}{32}''$ covered by a tape or a braid.
Larger than 500,000 C. M., $\frac{4}{32}''$ covered by a tape or a braid.

The requirements as to insulation and break-down resistance for wires for low-potential systems shall apply, with the exception that an insulation resistance of not less than 300 megohms per mile shall be required.

b. Must be always in plain sight and never encased except where required by the Inspection Department having jurisdiction.

c. Must be rigidly supported on glass or porcelain insulators, which raise the wire at least 1 inch from the surface wired over, and must be kept about 8 inches apart.

d. Must be protected on side walls from mechanical injury by a substantial boxing, retaining an air space of 1 inch around the conductors, closed at the top (the wires passing through bushed holes) and extending not less than 7 feet from the floor. When crossing floor timbers in cellars or in rooms where they might be exposed to injury, wires must be attached by their insulating supports to the under side of a wooden strip not less than ½ inch in thickness.

17. It is never advisable to bring high-potential wires into a building when it can be avoided. The danger to life due to their presence is greater than the fire hazard. An arc on a high-potential circuit carrying much current, once started, will continue to burn even when the points between which it plays are separated several inches; and a lightning discharge can easily start such an arc. High-potential systems of over 500 volts are usually alternating. Series-arc lighting circuits are the only important continuous-current high-potential circuits much used in the United States. With the exception of arc lamps, it is seldom necessary to bring any high-potential wires inside of buildings. Where alternating current is used, the line pressure is lowered by means of transformers, and it is never necessary to bring the high-pressure wires farther within than to substations or transformer rooms.

18. Transformers.—The ordinary alternating-current transformer consists of two separate coils of wire wound on

an iron core built up of thin sheets of iron. One of these coils, the *primary*, has a comparatively large number of turns and is connected to the high-pressure line. The other coil, the *secondary*, has a small number of turns and is connected to the lamps or other devices to be supplied with current. The high-pressure current flows through the primary and sets up an alternating magnetism through the secondary and induces an E. M. F. that is proportional to the ratio of the number of turns in the secondary coil to the number of turns in the primary. For example, if the primary had 500 turns and the secondary 50, the secondary voltage would be $\frac{50}{500}$, or $\frac{1}{10}$ the primary voltage, and if the primary were supplied at 1,000 volts, the secondary would deliver 100 volts. The following rules relate to transformers. Transformers of good reliable manufacture will stand all the tests named, but some of the old types made a number of years ago will not. Special attention should be paid to the rules governing the installation of transformers in buildings. Cut-outs on such circuits must be of some pattern especially designed and approved for the purpose. Ordinary fuse blocks should not be used for high voltages.

19. Rules Relating to Transformer Construction and Installation.—

Transformers—

a. Must not be placed in any but metallic or other non-combustible cases.

b. Must be constructed to comply with the following tests:

1. Shall be run for 8 consecutive hours at full load in watts under conditions of service, and at the end of that time the rise in temperature, as measured by the increase of resistance of the primary coil, shall not exceed 135° Fahrenheit.

2. The insulation of transformers when heated shall withstand continuously for 5 minutes a difference of potential of 10,000 volts (alternating) between primary and secondary coils and between the primary coils and core, and a no-load "run" at double voltage for 30 minutes.

c. Must not be placed inside of any building, excepting central stations, unless by special permission of the Inspection Department having jurisdiction.

d. Must not be attached to the outside walls of buildings, unless separated therefrom by substantial supports.

(*When permitted inside buildings.*)

a. Must be located at a point as near as possible to that at which the primary wires enter the building.

b. Must be placed in an enclosure constructed of or lined with fire-resisting material; the enclosure to be used only for this purpose, and to be kept securely locked and access to the same allowed only to responsible persons.

c. Must be effectually insulated from the ground and the enclosure in which they are placed must be practically air-tight, except that it shall be thoroughly ventilated to the outdoor air, if possible, through a chimney or flue. There should be at least 6 inches of air space on all sides of the transformer.

20. The greatest danger to be feared in the use of transformers is the grounding of the primary upon the secondary wires. This may occur either on account of a breakdown of the insulation under working conditions or because of lightning striking the primary wires. Efficient protection against lightning is an essential part of the out-of-door and central-station equipment.

WIRING FOR ARC LAMPS.

21. Constant-Potential Arc Lamps.—The use of arc lamps in multiple on low-potential circuits has already been considered. Wiring for these lamps is done in practically the same way as for incandescent lamps, so that no special comment is necessary. The following special rules relate to arc lamps operated on low-pressure circuits; a few rules relating to electric heaters are also given, as they belong to the same class of work.

Arc Lights on Low-Potential Circuits—

a. Must have a cut-out for each lamp or each series of lamps.

The branch conductors should have a carrying capacity about 50 per cent. in excess of the normal current required by the lamp to provide for heavy current, required when lamp is started or when carbons become stuck, without overfusing the wires.

b. Must only be furnished with such resistances or regulators as are enclosed in non-combustible material, such resistances being treated as sources of heat. Incandescent lamps must not be used for resistance devices.

c. Must be supplied with globes and protected by spark arresters and wire netting around globe, as in the case of arc lights on high-potential circuits.

Electric Heaters—

a. Must, if stationary, be placed in a safe situation, isolated from inflammable materials, and be treated as sources of heat.

b. Must each have a cut-out and *indicating* switch; i. e., a switch to indicate whether the current is "on" or "off."

c. Must have the attachments of feed-wires to the heaters in plain sight, easily accessible and protected from interference, accidental or otherwise.

d. The flexible conductors for portable apparatus, such as irons, etc., must have an *approved* insulating covering.

e. Must each be provided with name plate, giving the maker's name and the normal capacity in volts and amperes.

22. Constant-Current Arc Lamps.—Arc lamps used for street lighting are nearly always run in series. With this arrangement the same current flows through all the lamps and this current has to be maintained at a constant value by the generator, no matter how many lights may be in operation. The voltage generated by the dynamo therefore varies with the load. For example, suppose each lamp requires 50 volts; then, if 10 lamps were in operation, the

generator would have to supply a pressure of 500 volts; if 50 lamps, 2,500 volts; and so on. The current has to be forced through all the lamps in series; hence, the voltage increases directly as the load, while the current remains constant. This is just the reverse of the constant-potential system. It is easily seen that if the number of lamps is at all large, the pressure applied to the circuit has to be very high; hence, arc lamps connected to such a circuit must be treated as being on a high-pressure system and wired up accordingly. Series-arc lamps are used for indoor illumination, though not as extensively as they once were.

23. In all constant-potential installations, protective devices are installed to open the circuit whenever the lines are overloaded or the apparatus does not operate properly. *In constant-current working, the circuit must never be opened while the dynamo is running.* The protective devices used on constant-potential working must, therefore, never be installed on constant-current circuits.

All series-arc apparatus is thrown out of circuit by shunting or short-circuiting the main circuit before opening the lines upon which the apparatus is connected; in other words, the following rule must be complied with:

Switches—

Must, for constant-current systems, close the main circuit and disconnect the branch wires when turned "off"; must be so constructed that they shall be automatic in action, not stopping between points when started, and must prevent an arc between the points under all circumstances. They must indicate, upon inspection, whether the current be "on" or "off."

24. The general method of installing arc-lighting wires is similar to that used in other open work, except that the wires must be rubber-covered and mounted at least 8 inches apart. They must also be very thoroughly protected against accidental contact with anything not intended to connect with them. The following rules apply to the installation of the wires:

Wires for Use on Constant-Current Series-Arc Systems—

a. Must have an *approved* rubber insulating covering.

b. Must be arranged to enter and leave the building through an *approved* double-contact service switch, mounted in a non-combustible case, kept free from moisture and easy of access to police or firemen. So-called "snap switches" must not be used on high-potential circuits.

c. Must always be in plain sight and never encased except when *required* by the Inspection Department having jurisdiction.

d. Must be supported on glass or porcelain insulators, which separate the wire at least 1 inch from the surface wired over, and must be kept *rigidly* at least 8 inches from each other, except within the structure of lamps, on hanger boards, in cut-out boxes, or like places, where a less distance is necessary.

e. Must, on side walls, be protected from mechanical injury by a substantial boxing, retaining an air space of 1 inch around the conductors, closed at the top (the wires passing through bushed holes), and extending not less than 7 feet from the floor. When crossing floor timbers in cellars or in rooms, where they might be exposed to injury, wires must be attached by their insulating supports to the under side of a wooden strip not less than ½ inch in thickness.

The size of arc wires must not be smaller than that required by the Underwriters for the current used; but the wires should be much larger, on account of the loss in the lines and for mechanical strength. They should be of the same size as the wires used by the lighting company in its outside work, but must be rubber-covered, not weatherproof.

25. The tendency is to connect more and more arc lamps on a series circuit. In the early days of electric lighting, arc machines were made to operate 1, 2, or 3 lamps. The number was increased to 30 or 50, and finally to 60, where the limit remained for a few years. But

machines are now built to operate as many as 125 lamps on a single circuit, and are in quite general use, although the Underwriters prohibit the bringing of circuits of more than 3,500 volts (70 series-arc lamps) within buildings. With 45 volts at the arc and 5 volts lost on the line for each lamp, we have on a 125-lamp machine a total potential difference of 6,250 volts. A shock received through the human body from such a circuit is almost sure to be fatal. Too much care cannot be taken not only to insulate the wires and locate them out of reach, but also to insulate the lamps. They should be hung from insulated supports, and not hooks screwed into the ceiling.

Hanger Boards—

Must be so constructed that all wires and current-carrying devices thereon shall be exposed to view and thoroughly insulated by being mounted on a non-combustible, non-absorptive, insulating substance. All switches attached to the same must be so constructed that they shall be automatic in their action, cutting off both poles to the lamp, not stopping between points when started, and preventing an arc between points under all circumstances.

Arc Lamps—

a. Must be provided with reliable stops to prevent carbons from falling out in case the clamps become loose.

b. Must be carefully insulated from the circuit in all their exposed parts.

c. Must, for constant-current systems, be provided with an *approved* hand switch, also an automatic switch that will shunt the current around the carbons, should they fail to feed properly.

The hand switch to be approved, if placed anywhere except on the lamp itself, must comply with requirements for switches on hanger boards.

d. Must be carefully isolated from inflammable material.

e. Must be provided at all times with a glass globe surrounding the arc, securely fastened upon a closed base. No broken or cracked globes to be used.

f. Must be provided with a wire netting (having a mesh not exceeding $1\frac{1}{4}$ inches) around the globe, and an *approved* spark arrester, when readily inflammable material is in the vicinity of the lamps, to prevent escape of sparks, melted copper, or carbon. It is recommended that plain carbons, not copper plated, be used for lamps in such places.

Arc lamps, when used in places where they are exposed to flyings of easily inflammable material, should have the carbons enclosed completely in a globe in such manner as to avoid the necessity for spark arresters.

For the present, globes and spark arresters will not be required on so-called "inverted-arc" lamps, but this type of lamp must not be used where exposed to flyings of easily inflammable materials.

g. Where hanger boards are not used, lamps must be hung from insulating supports other than their conductors.

h. Spark arresters must so close the upper orifice of the globe that it will be impossible for any sparks thrown off by the carbons to escape.

26. Incandescent Lamps on Series Circuits.—The use of incandescent lamps connected in series for street lighting is quite extensive, but such lamps are rarely brought inside of buildings. When they are, the rules for other classes of high-potential work apply, as well as the following:

Incandescent Lamps on Series Circuits—

a. Must have the conductors installed as required by the rules for constant-current arc-lamp wiring and each lamp must be provided with an automatic cut-out.

b. Must have each lamp suspended from a hanger board by means of rigid tube.

c. No electromagnetic device for switches and no system of multiple-series or series-multiple lighting will be approved.

d. Under no circumstances can they be attached to gas fixtures.

Incandescent lamps used on series circuits must be designed and provided with fittings designed for that purpose. The rule against series-multiple connections means that a connection such as ten 52-volt lamps in multiple must not be

CURRENT REQUIRED BY MOTORS.

H. P.	Direct-Current Motors.			Alternating-Current Motors.								
				Single Phase.			Two Phase (4 Wire).			Three Phase (3 Wire).		
	110 V.	220 V.	500 V.	110 V.	220 V.	500 V.	110 V.	220 V.	500 V.	110 V.	220 V.	500 V.
1	9	4.5	2.0	14	7	3.1	6.4	3.2	1.4	7.4	3.7	1.6
2	17	8.5	3.7	24	12	5.3	11	5.7	2.5	13	6.6	2.9
3	26	13	5.6	34	17	7.5	16	8.1	3.5	19	9.3	4.1
5	40	20	8.8	52	26	11	26	13	5.5	30	15	6.4
7½	60	30	13	74	37	16	38	19	8.1	44	22	9.3
10	76	38	17	94	47	21	44	22	10	50	25	12
15	112	56	25				66	33	15	76	38	17
20	150	75	33				88	44	19	102	51	22
30	226	113	50				134	67	29	154	77	33
40	302	151	66				178	89	39	204	107	45
50	368	184	81				204	102	45	236	118	52
75	552	276	122				308	154	68	356	178	77
100	736	368	162				408	204	90	472	236	104
150	1,110	555	244				616	308	135	710	355	156
200	1,474	737	324				818	409	180	940	470	208

placed in series with a 10-ampere arc-lighting system. The burning out of 1 or 2 incandescent lamps on such a system would throw too much current on the others, burn them out, and destroy the sockets. Many other reasons forbid such connections.

WIRING FOR ELECTRIC MOTORS.

27. The wireman is frequently called upon to connect up motors. These are nearly always operated at constant potential, and the wires are installed as for other wiring of this kind. They are usually operated on 110, 220, or 500 volts direct current or on similar voltages alternating current. Alternating-current motors are usually run on either the two- or three-phase system. Care should be taken to see that the interior wiring has sufficient capacity, and in order to determine this, the current taken by the motor at full load should be known.

It is well to allow a liberal amount of current for small motors, because of their low efficiency. The efficiency of a large motor can be learned from the manufacturer; and high-grade, high-priced machines are more efficient than cheap ones. This is a most important consideration to the purchaser. For the purposes of wiring, however, it is safe to figure 90 per cent. efficiency for motors over 10 horsepower in capacity, 85 per cent. for motors of 5 horsepower or over, 80 per cent. for motors of 2 horsepower or over, 75 per cent. for motors of 1 horsepower, and lower efficiencies for motors of smaller sizes. There are 746 watts to a horsepower. Alternating-current motors take somewhat more current for the same output than those operated on direct current. The accompanying table gives the approximate value of the current in the lines for motors of various sizes and voltages. These figures would vary somewhat in individual cases, because the efficiency and other characteristics of motors vary considerably. The current taken by a motor at full load is usually given by the makers on the name plate of the machine. If it is not given, the table will serve as a guide in determining the size of wire to be used.

After the full-load current of the motor has been determined, the size of the wire is arrived at in the same way as if the wiring were being done for lights.

28. Motors should not have much drop in the wiring, or they will not regulate properly; but drop upon motor circuits does not affect motor regulation to the same extent as drop on lighting circuits affects the light. The following rules relate to the installation of motors:

Motors—

a. Must be insulated on floors or base frames, which must be kept filled to prevent absorption of moisture, and must be kept clean and dry. Where frame insulation is impracticable, the Inspection Department having jurisdiction may, in writing, permit its omission, in which case the frame must be permanently and effectively grounded.

A high-potential machine which, on account of great weight or for other reasons, cannot have its frame insulated, should be surrounded with an insulated platform. This may be made of wood mounted on insulating supports and so arranged that a man must stand upon it in order to touch any part of the machine.

In case of a machine having an insulated frame, if there is trouble from static electricity due to belt friction, it should be overcome by placing near the belt a metallic comb connected to the earth or by grounding the frame through a very high resistance of not less than 200 ohms per volt generated by the machine.

b. Must be wired under the same precautions as required by rules for wires carrying a current of the same volume and potential.

The leads or branch circuits should be designed to carry a current at least 50 per cent. greater than that required by the rated capacity of the motor to provide for the inevitable overloading of the motor at times without overfusing the wires.

c. The motor and resistance box must be protected by a cut-out and controlled by a switch, said switch plainly indicating whether "on" or "off." Where $\frac{1}{4}$ horsepower or less is used on low-tension circuits, a single-pole switch will be accepted. The switch and rheostat must be located within sight of the motor, except in such cases where special

permission to locate them elsewhere is given, in writing, by the Inspection Department having jurisdiction.

d. Must have their rheostats or starting boxes located so as to conform to the requirements of other resistance boxes.

In connection with motors, the use of circuit-breakers, automatic starting boxes, and automatic underload switches is recommended, and they *must* be used when required.

e. Must not be run in series-multiple or multiple-series, except on constant-potential systems, and then only by special permission of the Inspection Department having jurisdiction.

f. Must be covered with a waterproof cover when not in use, and if deemed necessary by the Inspection Department having jurisdiction, must be enclosed in an approved case.

From the nature of the question the decision as to what is an approved case must be left to the Inspection Department having jurisdiction to determine in each instance.

g. Must, when combined with ceiling fans, be hung from insulated hooks, or else there must be an insulator interposed between the motor and its support.

h. Must each be provided with a name plate, giving the maker's name, the capacity in volts and amperes, and the normal speed in revolutions per minute.

29. Motor starting boxes with automatic release, to open the circuit if the motor is overloaded or if the current is cut off for any reason, such as the opening of the main switch, have come into very general use. They are a very great protection to the motors, and are much more convenient than the old starting boxes. Automatic circuit-breakers can be installed to answer very nearly the same purpose.

The Underwriters' rules prohibit the operation of motors or lights from street-railway circuits, except in street cars, car barns, or railway power houses. The reason for this is that one side of a railway system is grounded to the rails, and the installation of motors or lights would always introduce more or less fire risk.

BELL WIRING.

30. Electric bells, burglar alarms, and electric gas-lighting appliances bring in another class of wiring with which the wireman has to deal. If these appliances are put in properly, they may be a great convenience; if not, they are continually getting out of order and may prove to be a regular nuisance. This class of work is often slighted and put up in a cheap manner, but it will pay in the end to have it put up carefully. The bells and annunciators which show from what point the bell was rung are operated by primary batteries, which are of low voltage, and no fire hazard is introduced if the bell wires are kept well separated and insulated from electric light and power wires.

THE ELECTRIC BELL.

31. The electric bell is a very simple piece of apparatus. In Fig. 5 is shown a type of skeleton bell, in which all the parts are visible. The battery wires are connected at the terminals t, t', and the course of the current is as follows: From the terminal t to the adjustment screw s, which is tipped with platinum in order to prevent oxidation of the contact surface, through the spring l and the end p of the armature to the coils of the magnets m, m', and out at the terminal t'. When no current is passing, the armature is held away from the poles of the electromagnets, as in the position shown, but as soon as a battery circuit is closed and a current sent through the coils, the magnets become energized and attract the armature a, which swings about the pivot p, causing the

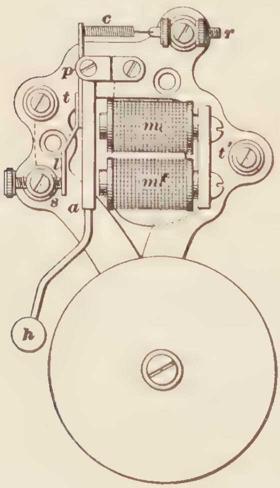


FIG. 5.

hammer *h* to strike the bell. This movement breaks the circuit between *s* and *l*, and the iron cores being thereby demagnetized, the spring *c* draws the armature away, when the spring *l* again touches the screw *s*, completing the circuit. As long, then, as the battery current is free to flow, this vibration of the armature and hammer will continue. The tension of the release spring *c* may be changed to suit the strength of the battery by means of the regulating screw *r*, which is provided with nuts for this purpose on each side of the supporting pillar. The bell mechanism is usually enclosed to prevent entrance of dust or insects, which may interfere with the working of the bell by lodging on the contact points, thereby preventing the current from passing through the magnets.

32. The bell just described is of the common vibrating class. When a bell is required to give a single stroke each time the circuit is closed, that is, for each pulsation of current, a slight difference in the connection of the ordinary bell is necessary. A wire is connected between the end of the magnet coil *m* and the terminal *t*, so that the circuit is simply from one terminal to the other through the coils. Hence, when a current passes through the coils, the armature is attracted and held, a single stroke being given to the bell; on interrupting the current, the armature is drawn back to its normal position by the spring *c*.

33. The **buzzer,** shown in Fig. 6, is used in places where an electric bell would be undesirable, as in small, quiet rooms or on desks, and is constructed on the same principle as the bell except that the armature does not carry a hammer. In the illustration, the cover *c* is removed, showing the magnet coils *m*, *m'* and the armature *a*. An adjusting screw *s* is provided to regulate the stroke of the armature and the consequent intensity of sound. The wires from the push button and battery are secured at *d* and *e*, and on closing the circuit, the rapid vibration of the armature causes a humming or buzzing sound, whence the name.

Buzzers are generally used for signaling between the dining room and kitchen, as a bell usually makes too much noise for this purpose.

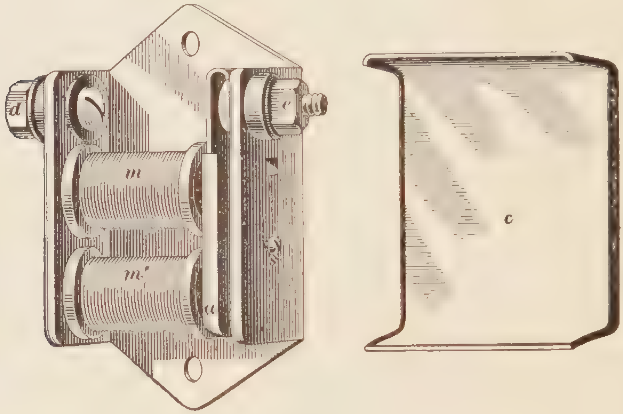


Fig. 6.

34. The circuit-closing devices used on bellwork usually take the form of a **push button.** These are made in all sorts of styles. The very cheap ones are seldom satisfactory. Bronze push buttons should be used where exposed to the weather. Fig. 7 shows the ordinary round push button. The wires enter through holes in the base and attach to springs *b* and *c*. The cover *d* screws on, and when *e* is pushed, *b* and *c* come together, thus completing the circuit.

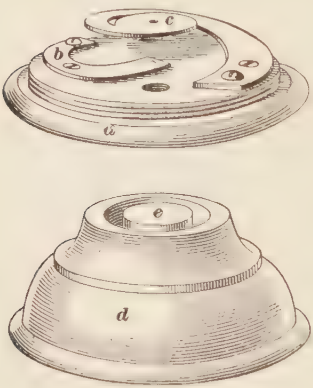


Fig. 7.

One cell of any good type of battery will ring a good bell over a short length of wire, but it is never advisable to rely upon less than 2 cells even on the smallest installations. When several cells are connected together to form a battery, the zinc of one must be joined to the carbon of the next and the free

terminals at the ends of the row of cells connected to the line wires.

35. Electric bells can be had of all sizes, from mere tinklers up to the largest fire gongs. Very cheap bells should not be used. They require much battery power, and soon get out of order. Trouble is usually found first at the contact points or the armature pivot. Contact points should be tipped with platinum or silver; platinum being much the better material for this purpose, as it never corrodes or tarnishes, but it is more expensive than silver, which is much used.

36. In an ordinary dwelling there are usually not less than three electric bells, one located at a convenient point in the hall with a push button at the front door; one in the kitchen with a push at the back door, and one, a buzzer, located in the kitchen with a push in the dining-room floor. These bells may all be operated by the same battery. The battery should be placed in a cool place, but where it never is cold enough to freeze; preferably in the cellar, where the air is not so dry that the water in the cells evaporates rapidly. Cells should not be allowed to become dry. Water should be added from time to time so as to keep the level of the solution up to the proper height, which is usually marked on the glass jar.

BATTERIES.

37. Many different types of cell are manufactured that are suitable for bellwork. Most of those used for bellwork are of the **open-circuit** type. They are intended to furnish current for short intervals only and will run down if used continuously. Crosses between the wires or grounds will often cause the cells to run down rapidly. Most of these cells will recover to a certain extent if allowed to stand for a while on open circuit, but they should never be allowed to become short-circuited if it is possible to avoid it.

The cells in ordinary use on bellwork have electrodes of zinc and carbon and contain a solution of sal ammoniac (ammonium chloride). Sometimes they also contain a "depolarizing" agent, such as manganese dioxide. The effectiveness of a carbon-zinc cell depends largely on the materials of which the carbon element is made and the skill used in its manufacture. Burning the carbons too much or too little in the process of manufacture makes them inferior. Some manufacturers make inferior carbons and then treat them with sulphuric acid, to make them operate with vigor when first installed. Such cells soon become polarized, and in the course of a few weeks or months are very inferior, not because of the acid so much as because of the poor quality of the carbon.

Where batteries are to stand considerable use, cells with depolarizing agents must be employed. Where batteries are worked very severely, being in almost constant use, more expensive cells must be employed. Where there are facilities for charging, storage batteries are very convenient for this kind of work. Dry cells are used to a considerable extent in connection with light bellwork and portable electrical devices. There are many varieties of electric cells, some of which are very useful and economical, but they all require more or less care. The study of the merits and demerits of these devices is not within the scope of this Course.

38. The Leclanché Cell.—Fig. 8 shows a type of cell that has been largely used for bellwork. It consists of a porous cup *P*, containing the carbon electrode *C*, to which a binding post *B* is attached; also a zinc rod *Z*, both being enclosed in a glass jar with a contracted top. The zinc rod is provided with a binding screw B_1, which serves as the negative terminal of the cell, *B* being the positive terminal. Before the battery will furnish current, the jar must be filled to the point shown in the cut with a saturated solution of sal ammoniac, and in connecting up, the zinc of one jar is joined by a short piece of wire to the carbon of the

next. This gives the series grouping, which is usually required in bellwork. When, after considerable use, the current from the cells becomes feeble, it will be necessary to replace the liquid, but it frequently happens that the power may be restored by the addition of a little water to make up for evaporation. The zinc will in course of time be consumed, and must be replaced, and the sal ammoniac may also be renewed at the same time, although it should last longer than a single zinc rod of the usual size ($\frac{3}{8}$ inch diameter). After five or six rods have been used, the material inside the porous cup will no longer act effectively, and this means practically a new carbon and cup, since they may be procured very cheaply. In the case of renewal of a large number of cups, they may be returned to the manufacturer and recharged by him.

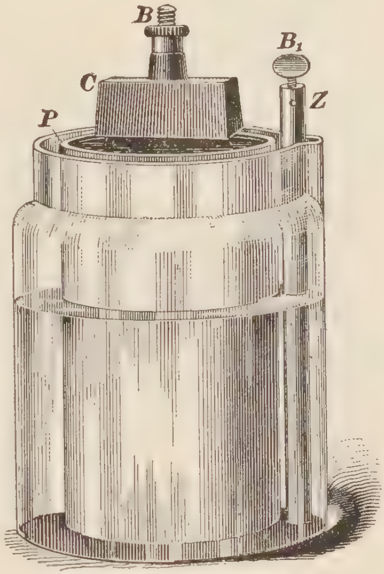


FIG. 8.

39. Carbon cylinder cells are a modified form of the Leclanché. Sal ammoniac is used as the exciting fluid, or electrolyte, but the porous cup is omitted. In its place a carbon cylinder is used that presents a large surface, and hence makes the cell have a low internal resistance.

ANNUNCIATORS.

40. When a number of push buttons are installed, it is necessary to have an indicating arrangement to show from which button the bell is rung. The instrument used is

called an **annunciator.** One ordinary house style is shown in Fig. 9. On the face are rows of small windows, before one of which an indicator appears when the bell rings, showing from which room the signal has been sent. A handle *h* at the side is intended to be used to restore the indicators to their normal position when the call is answered. A view of the indicator itself is given in Fig. 10. A hinged arm *a* carries a card bearing the name or number of the room to which the drop is connected, and is held up in the position shown by a counterbalanced trip *t* in front of an electromagnet *m*. As soon as the current passes through the electromagnet, the trip is attracted and the indicator falls, being then visible from the outside through one of the openings in the front.

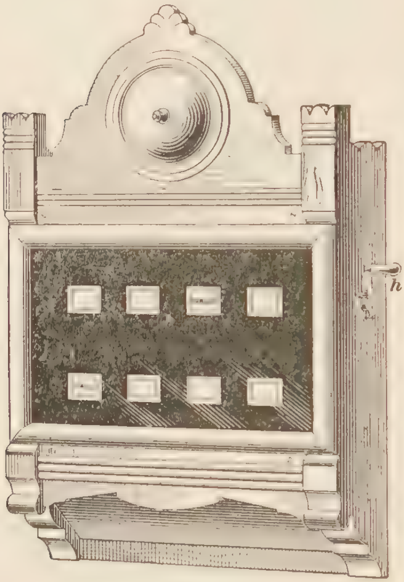


FIG. 9.

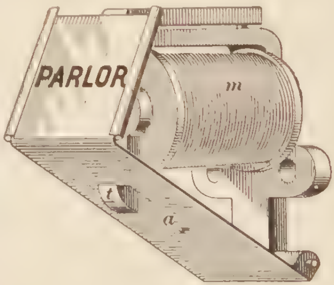


FIG. 10.

41. The **needle annunciator,** Fig. 11, is a style much used in hotels and for elevators. The current on passing through the electromagnet of an indicator attracts a pivoted, iron armature carrying a pointer *P* on the outside dial, causing it to set in an oblique position, in which it is held by a catch until released by pressing the knob *k* below the case. Annunciators may be obtained in almost any desired

finish and for any number of drops. One type that has lately become very popular is the **self-restoring annunciator.** In the ordinary instrument the drops must always be put back after a call comes in. Sometimes this is not done, and consequently one is at a loss to know, when several are down, which button has been pushed. Self-restoring annunciators are constructed so that when a button is pushed, its corresponding drop falls and remains down until the next call is sent in. This operates a magnet that moves the restoring device and resets the first drop. Self-restoring annunciators are somewhat more liable to get out of order than the simple kind and some of them require more battery power. They are, however, a great convenience, and are rapidly finding favor. They are wired up to the buttons in the same way as an ordinary annunciator, as the restoring device is wholly within the annunciator itself.

FIG. 11.

RUNNING BELL WIRE.

42. There are no regulations governing the insulation used on bell wire. That generally used is known as *annunciator wire* and is usually No. 16 or No. 18 B. & S. copper-covered, with two wrappings of cotton treated with paraffin. This wire is cheap, but it is not moisture-proof, and the insulation does not adhere very firmly to the wire. However, it will work satisfactorily if it is carefully put up and is run in a dry place. For really good work, *weather-proof office wire* should be used. The insulation on this wire is heavier than on the annunciator wire and adheres firmly; it is also damp-proof. If it is necessary to run bell wires where they will be exposed to considerable moisture, the best plan is to use rubber-covered wire.

The size of wire used is generally No. 16 or No. 18 B. & S

It will pay to use nothing smaller than No. 16, because the cost is very little more and the line resistance is thereby reduced. Also the batteries work to better advantage and the line is mechanically stronger. For the main-battery wire in large installations, No. 14 may be used to advantage.

Bell wires are often stapled to woodwork, especially when bells are installed in old houses. If any stapling is done, care should be exercised not to drive the staples so hard that they cut through the insulation and break the wire. Do not fasten two wires down under the same bare staple. Special staples, using a small saddle of leather between the wire and the top of the staple, are made for this work. When bell wires are run in new buildings, they may usually be run through holes in the beams, and they should be grouped together as much as possible. By doing this, the wires are run in an orderly manner and very little stapling is needed.

In the best class of work, bell wires are sometimes run in conduits, but no matter how they are run, all circuits should be carefully tested out after they are put up to make sure that there are no grounds, breaks, or crosses. See that all bell wires are kept well away from electric-light wires.

BELL AND ANNUNCIATOR CIRCUITS.

43. Simple Bell Circuit.—A simple bell circuit is shown in Fig. 12. A battery of two Leclanché cells *c*, *c* connected in series furnishes current to the bell *b*, located at any part of the house, and the push button *p* is placed at any convenient point.

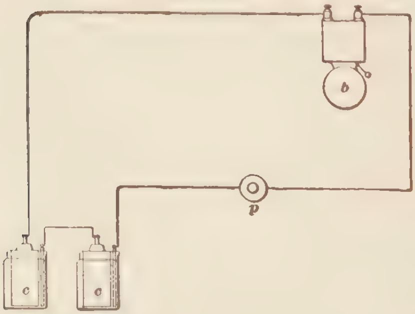


FIG. 12.

44. Two Bells Operated From One Point.—It is frequently necessary to ring two or more bells from one push button.

This may be accomplished by one of two methods. One is to connect the bells in multiple arc across the leads, as in Fig. 13, so that each one is independent of the others, the bells *a*, *b* being on separate branches. The battery *B* is represented in this diagram in the manner generally adopted, the fine line indicating the carbon of the cell and the heavy line the zinc. The other method, making use of a series arrangement, is shown in Fig. 14. This is often preferred to the first method, because there is usually a saving of wire in its use, but it is necessary to change all but one of the bells to single stroke. The reason for this is that, unless the bells were exactly similar in their adjustment, the period of vibration, or rate of swing, of the armatures would be different, and the interference would prevent satisfactory ringing of the bells. If, however, one bell is free to vibrate and the rest are all changed to single stroke, very little adjustment of each one will be required to produce a strong clear ring.

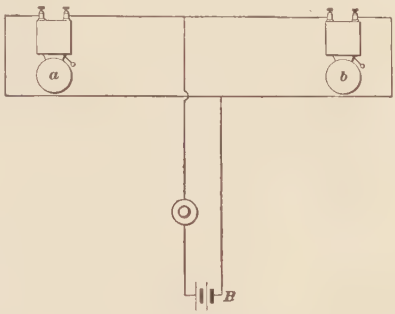


FIG. 13.

FIG. 14.

45. One Bell Operated From Two Points.—When it is desired to ring a bell from two different places, a simple series circuit cannot be used, because there would be a break at each

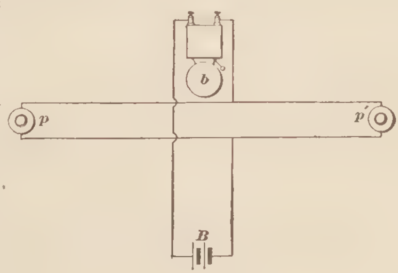


FIG. 15.

push button and a current would not flow unless both buttons were pressed at once. The second button must then be in parallel to the first, as in Fig. 15, so that whichever button p or p' is pressed, the circuit through the bell b and battery B is completed.

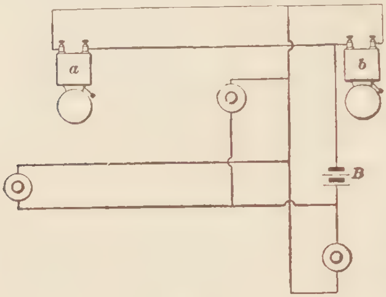


FIG. 16.

46. Figs. 16 and 17 show two arrangements of wiring for ringing two bells simultaneously from three different points. The bells a, b are connected in parallel in Fig. 16, but they may be put in series, if desired, as in Fig. 17, provided one of them is changed to single stroke. In the case of an actual installation, it might be necessary to run the wires in some other manner than as here laid out, depending on the construction of the building; but, from the directions already given, it should be an easy matter to devise the best arrangement. The choice between series and parallel connection of the bells will depend on which is more economical in copper for the line wires.

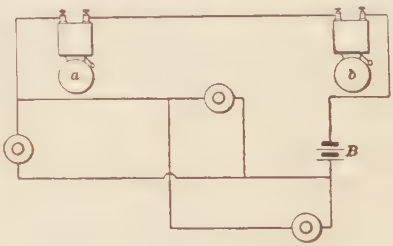


FIG. 17.

Placing the bells in multiple requires a larger volume of current to be supplied than when they are in series, because the total current subdivides among all the bells. This calls for a large battery and large wires. When the branch circuit containing one bell is very much longer, and hence of higher resistance than the branch containing another bell, the current will not divide equally between the two bells, and hence the parallel arrangement may not be satisfactory in such cases. Placing the bells in series requires an additional cell or two, but no larger wire is required.

47. Wiring for Three Bells and Three Push Buttons.—Fig. 18 shows a plan of wiring that is often used for

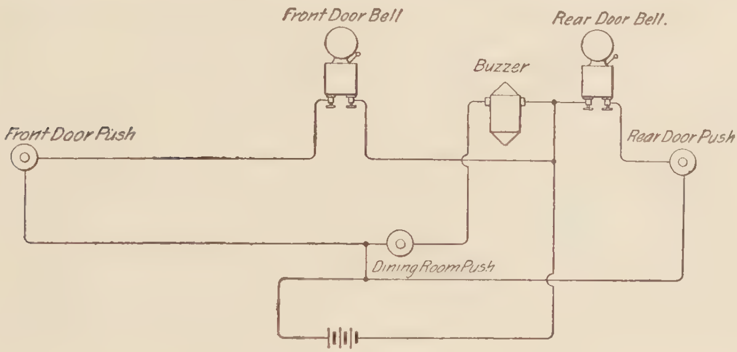


FIG. 18.

the bell system in a small dwelling where no annunciator is used.

48. Wiring for Simple Annunciator.—A wiring diagram for a simple annunciator system is shown in Fig. 19. The pushes *1*, *2*, *3*, etc. are located at convenient points in the various rooms, one terminal being connected to the battery wire *b* and the other to the leading wire *l* communicating with the annunciator drop corresponding to that room. The battery wire is run from one pole of the battery direct to one side of each of the pushes. The other side of each push is then connected to its drop on the annunciator. A battery of three or four Leclanché cells is placed at *B* in any convenient location, but should not be set in a dark or inaccessible spot or be exposed to frost.

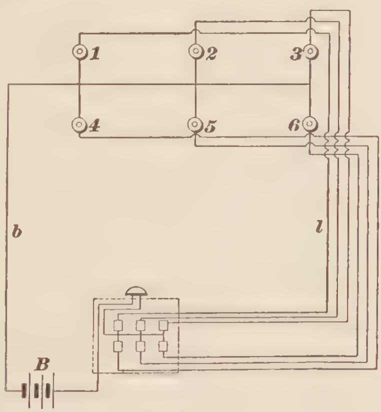


FIG. 19.

49. Wiring for Return-Call Annunciator.—In Fig. 20 is illustrated a return-call system requiring one battery wire *p h b*, one return wire *r*, and for each room one leading wire l_1, l_2, etc. The annunciator board is divided into two parts, the upper part having the numbered drops and the lower the return-call pushes. Each room is provided with a double-contact push, such as that shown in Fig. 21. The tongue *t* makes connection normally with the upper contact *c*, but when pressure is put on the button *k*, the tongue is forced against the lower contact *c'*. The return-call pushes on the lower board of the annunciator are of the same description. In Fig. 20 all

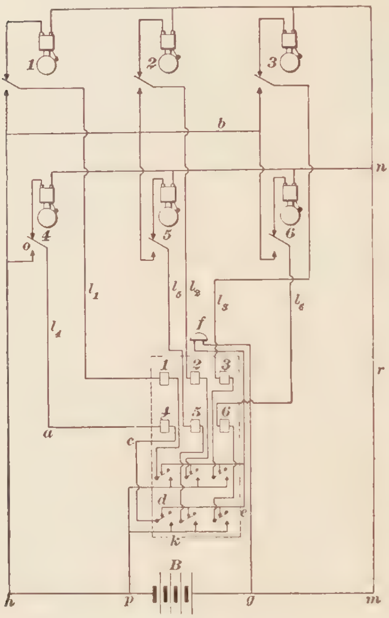


FIG. 20.

these pushes are shown diagrammatically, for convenience in tracing out the circuits. The closure of the circuit in any room, as, for example, No. *4*, releases the corresponding drop and rings the office bell *f*. The path of the current is then from the push *4* through *c–d–e–f–g–B–h–o*, and back to the lower contact of the push button. On the return signal being made from the office, the annunciator-bell circuit is broken at *d*, and, the push button in the room

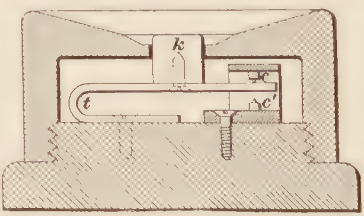


FIG. 21.

being released, a new circuit is formed through *k*, as follows: from the battery *B* through *g–m–r–n–o–a–c–k–p* to the battery, the room bell being in this circuit.

50. In installing annunciator systems, it is usual to run the battery wire, which is No. 14 or 16 annunciator wire, through the building at some central portion. If there are many rooms, it will be advisable to splice on a length of No. 18 wire to extend from the push in each room to the battery wire. The connection from the other side of the push button to the annunciator, that is, the leading wire, should be No. 18. For the return-call system, a battery of four or five Leclanché cells is required.

All wires used in annunciator service should have distinguishing colors to prevent confusion. The battery wire may be blue, the return wire red, and the leading wires white. This arrangement will greatly simplify the connections and reduce the liability of mistake.

51. Wiring for Elevator Annunciator.—The wiring for an elevator annunciator does not differ greatly from that of a simple annunciator; in fact, the scheme of connections is essentially the same. A battery wire *b*, Fig. 22, is run up the shaft and connected to each push button on the different floors. The return wires from each button are then carried to a point *a* at the middle of the shaft, where they should terminate in a small connection board, so that they may be readily disconnected from the wires in the cable running to the cage *e*. The wires running from the connection board to the cage are in the form of a flexible cable, which is made especially for this kind of work. This cable contains one more wire than there are push buttons, because it has to provide for the return wire *r*.

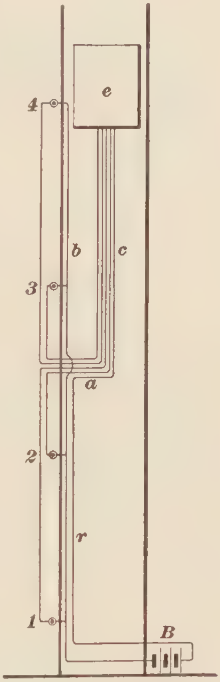


FIG. 22.

SPECIAL APPLIANCES.

52. The Automatic Drop.—For special alarm purposes, it is sometimes desirable that the bell should continue to ring after the push is released. This is accomplished by the use of an **automatic drop**, which closes an extra, or shunt, circuit as soon as a current passes along the main circuit.

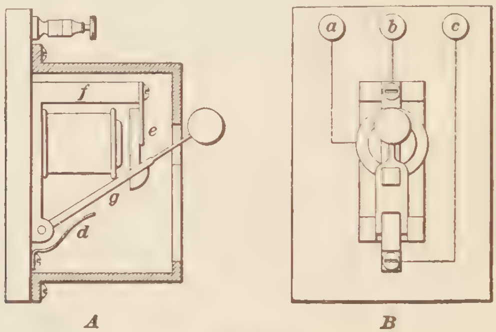


FIG. 23.

Fig. 23 shows two views of an automatic drop, *A* being a side elevation and *B* a front view with the cover removed. There are three terminals on the baseboard; those marked *a* and *b* are connected to the ends of the magnet coil, the end at *b* being also connected to the frame *f*; terminal *c* makes connection to the spring contact *d*, which is insulated from the frame and all other wires. The bell circuit is closed first through *a*–*b* by means of the push button; the armature *e* is at once attracted, thereby releasing the rod piece *g*, which falls by gravity and makes contact with the spring *d*, establishing a circuit between *b* and *c*, which short-circuits the push button and magnet coil of the drop.

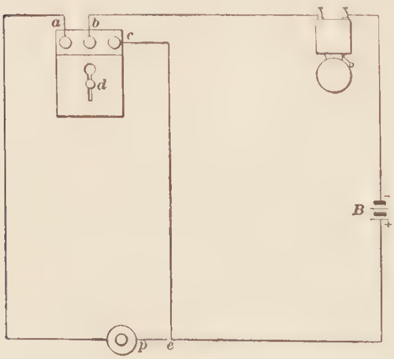


FIG. 24.

53. The connections for the automatic drop are shown in Fig. 24. The

circuit obtained, on pressing the push button p, is from the positive pole of the battery B through the push to the terminal a of the drop, through the magnet coils to b, and then through the bell to the negative pole of the battery. As soon as d falls, the magnet coils are cut out, the current being diverted at c, and passes by way of the new contact from c to b, and thence through the bell and back to the battery.

54. Two-Point Switch.—When two bells are arranged to ring from one push button, it is sometimes desirable to cut one of them out during some part of the day. For this purpose a small switch, Fig. 25, is used, by means of which one bell, when connected in series with the other, may be short-circuited. The wires are run to the back of the switch, one connection being to the lever arm at a, the other to the contact piece b.

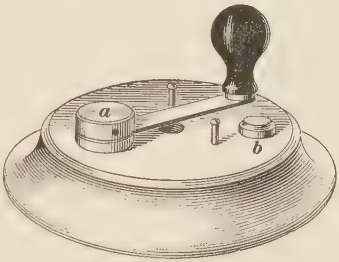


FIG. 25.

55. Door-Openers.—In apartment houses, banks, and other places, it is often convenient to have the latch on a door arranged so that the door may be unlocked from some distant point. For this purpose **door-openers** are used. These are made in a number of different styles, the mechanism differing with the different makes. In all of them, however, the unlocking is effected by means of an electromagnet, which is connected to the push and battery in the same way as an ordinary bell.

56. Operating Bell From Lighting Circuit.—It is sometimes convenient to operate an electric bell from an incandescent lighting circuit. This may be done where direct current is used to operate the lamps, but if alternating current is used, an ordinary bell will work very poorly, if at all. Of course, it is necessary to use a resistance in connection with

the bell in order to limit the current. The amount of resistance will depend on the kind of bell used, because some bells require much more current than others. Incandescent lamps make a cheap and convenient form of resistance. Fig. 26 (*a*) shows a bell *a* and push button *b* in series with 4 lamps *l* across a 110-volt circuit. This is the simplest scheme of connection, but there is apt to be bad sparking at the contacts on the bell, because the voltage across the break rises to

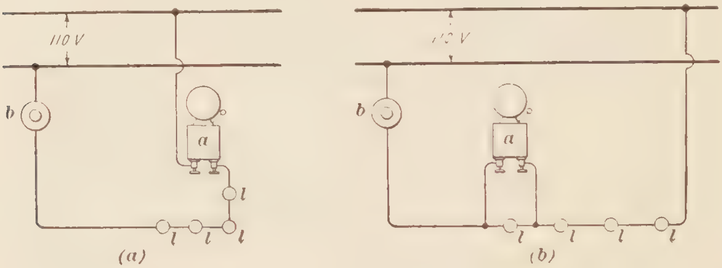


FIG. 26.

110 volts at the instant the circuit is broken. (*b*) shows the bell shunted across one of the lamps, in which case the voltage at the break would be much smaller. The operation of bells from lighting circuits is not to be recommended unless the bell wiring is done as carefully and with a view to as good insulation as the light wiring. Ordinary bell wiring put up with staples, etc. should *not* be connected to any source of pressure exceeding 10 volts, and it would be decidedly unsafe to connect it to a 110-volt circuit.

BURGLAR ALARMS.

57. Automatic switches may be placed on windows and doors, in connection with alarm bells, to indicate when entrance into a building is being forced. There are two methods of installing these alarms: the open-circuit and the closed-circuit systems. In the **open-circuit system,** which is the one usually employed, the connections are similar to those of an ordinary electric-bell circuit, the automatic

circuit-closing device being substituted for the push button. A window spring used in this system is shown in Fig. 27. This is let into the window frame, the cam *c* alone projecting; when the window is raised, the cam is pressed in, revolving about the pin *p*, and makes contact with the spring *s*, which is insulated from the plate by a washer at the lower end and is normally prevented from touching the cam by an insulating wheel *w*. The wires from the bell and battery are connected to the plate and spring, respectively. The annunciator used is much the same as that employed for bellwork, but additional, convenient attachments are usually placed on it, such as a device to keep the bell ringing until the annunciator is reset, a clock to connect and disconnect the system at certain hours, etc. The annunciator is usually equipped with a small button over each drop, which when pushed will complete the circuit and cause the drop to fall if there happens to be any door or window open. These are very useful for testing out to see if everything is closed. All these appliances belong to the annunciator itself and do not affect the general plan of wiring, which is carried out in the same way as for bell wiring.

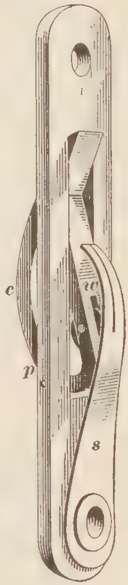


FIG. 27.

58. In the **closed-circuit system,** automatic switches of various styles are used, but the contacts are held together

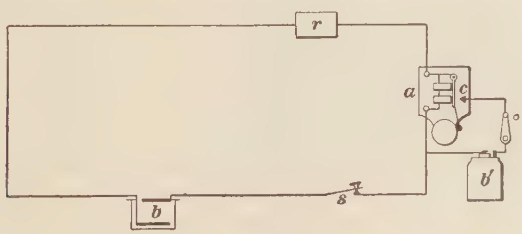


FIG. 28.

when the alarm is set, and a movement of the window or door breaks this contact. Two batteries are required for

this system, one being a closed-circuit gravity battery indicated at *b* in Fig. 28, connected in series with a resistance *r* of about 200 ohms, the magnet coils of the bell *a*, and the alarm switch *s*. The armature of the bell is thus held away from the back contact *c*. The open-circuit Leclanché battery *b'* is connected to this contact and to the far terminal of the magnet coils; this circuit is therefore normally open, but as soon as the main circuit is opened by moving the alarm switch, the spring on the armature of the bell presses it against the back contact, thereby closing the local circuit through the bell.

59. Fig. 29 shows a **crowfoot** or **gravity** cell, the type generally used when a small current has to be furnished continually. A sheet-copper electrode is placed at the bottom of the jar along with crystals of copper sulphate. A solution of zinc sulphate covers the zinc, and on account of the copper-sulphate solution being more dense than the other, the two solutions do not mix, hence the name gravity battery. The top solution should be drawn off from time to time and water added. If the dividing line between the solutions gets up as high as the zinc, a dark deposit will be formed on the zinc and the battery will become inoperative. This upward diffusion of the copper sulphate will occur if the cell is left standing

FIG. 29.

on open circuit. These cells will deliver a small, steady current, but their output is not large and they are rather expensive to maintain. The closed-circuit burglar-alarm system is little used in ordinary work in connection with dwellings.

It is usual when connecting up burglar-alarm annunciators to group the windows or doors; i. e., the contacts on several doors or windows are connected in parallel and attached to one drop. To provide a drop for each door and window would require too large an annunciator and would cost too much for the ordinary run of work.

ELECTRIC GAS LIGHTING.

BURNERS FOR PARALLEL SYSTEM.

60. In the application of electricity to gas lighting, a spark is caused to pass between two conductors, placed near the burner, at the same time that the gas is turned on. In the **parallel system** of lighting, each burner is independent of all the others, having direct connection between the battery wire and ground. Three different styles of burner are used: the *pendant*, the *ratchet*, and the *automatic* burner.

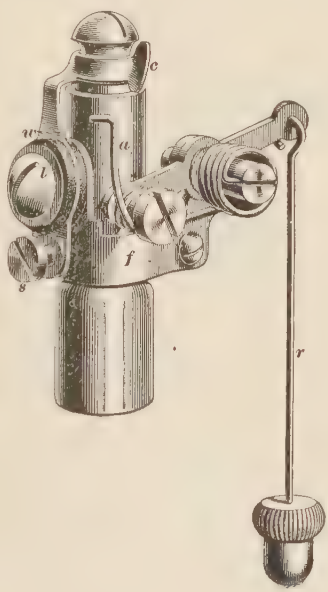


FIG. 30.

61. The **pendant burner** is shown in Fig. 30. A well-insulated wire is brought to the burner and secured under the head of the screw *s*, thereby making connection to the stationary contact piece *c*, which is fastened by a screw *l* to the frame *f* and insulated from it by washers *w*. On pulling the pendant *r* downwards, the spring *a*

is drawn across c, and, on passing off at the upper side, the break causes a spark which, when the gas has been turned on, will ignite it.

62. The **ratchet burner** is very similar to the plain pendant, but is provided with a ratchet and pawl operated by a pendant, a downward pull turning on the gas at the same time that the spark is produced. A second pull extinguishes the gas.

63. The **automatic burner** is shown in Fig. 31 with the cover removed. Two wires must be provided, running from a double push button, one of them leading to the wire a and the other to b. The circuit from a is through the left-hand magnet coil c to the insulated band d, which has a projection e at one side. Upon this rests a metal rod r, bent at the upper end and terminating in a contact piece; at the lower end the rod is grounded by connection with the frame f. Each magnet coil has an armature g or g' with a projecting finger on the inner side. When current is sent through the magnet c, the armature g is raised and turns the gas valve v by striking one of the pins. At the same time the rod r is pushed up, thus breaking the circuit at a point where the gas is escaping and producing a spark that will ignite it. To provide for certain action, the sparking should continue later than the instant of turning on the gas, and this is effected by the use of a spring to restore the circuit. The

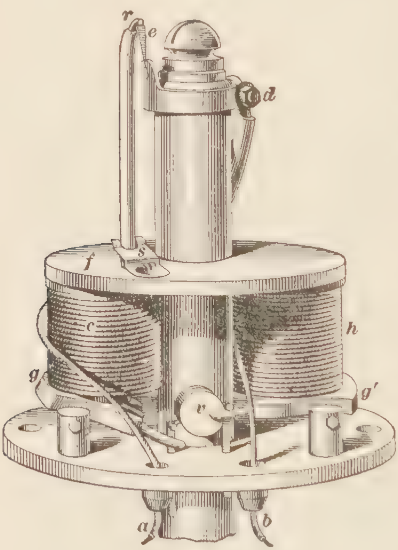


FIG. 31.

rod r is forced upwards against the spring s, but when the circuit is opened at the spark gap, the spring presses the rod and armature down again, and the circuit being thereby closed, a spark is again produced on opening. This continues as long as the push button is pressed, the action being similar to that of an electric bell. The second coil h is grounded at the inner end, and when a current is sent through, the armature g' is raised, turning the valve and cutting off the supply of gas. Automatic burners are very convenient where it is wished to light or extinguish a gas jet from some distant point. They are used principally in hallways where it is desired to light or extinguish the gas from any floor.

ARRANGEMENT OF LIGHTING APPARATUS.

64. To light gas by electricity, a spark of considerable intensity must be produced. This can be done by means of batteries and induction coils or by an electrostatic discharger. For the parallel system used with the burners just described, a **spark coil** is employed to supply a good spark. Fig. 32 shows an ordinary spark coil. It is made up of an iron core about $\frac{3}{4}$ inch in

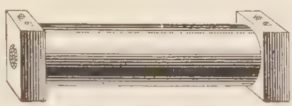


FIG. 32.

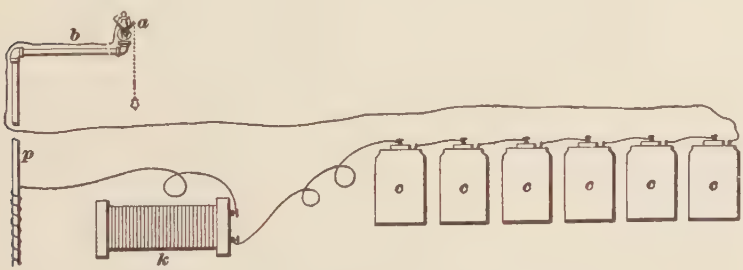


FIG. 33.

diameter and 8 inches long. This core is built up out of

soft-iron wire and is wound with 5 or 6 layers of No. 18 magnet wire. The coil *k* is connected in series with the cells *c*, as indicated in Fig. 33. The battery should have at least six cells for satisfactory service. One end of the coil is connected to the gas pipe *p*. When the pendant is pulled, the tip makes contact and a current is established through the circuit. When the circuit is broken, the self-induction of coil *k* causes a bright spark at the break.

65. Wires for this purpose are usually run on the outside of the gas fixtures, but they may be concealed if there is sufficient room between the fixture shells and the gas pipe. It is advisable to use wire provided with good insulation for this kind of work, for the wires are particularly likely to become grounded upon the fixtures to which they are fastened. Where fixtures are wired on the outside, the wires should be painted or made with the proper colored insulation, so as not to show; but they must not be painted with bronze or metallic paint, which would penetrate the insulation and cause grounds, unless rubber-covered wire were used.

66. To make the location of grounds easy, it is advisable to run separate wires from a distributing point near the battery to each fixture or group of fixtures. The wires can be connected together at that point by means of a connecting board, at which any fixture can be disconnected. This makes the location and removal of grounds an easy matter. Fig. 34 shows the general arrangement of a system using both plain pendant and automatic burners. The distributing board is shown at *D*. The automatic burner is provided with a double push button *c*. When the dark button is pressed, the light is extinguished; when the light button is pushed, the gas is turned on and lighted.

In the above diagrams the gas pipe has been used as part of the circuit. This is done where the fixtures use gas only. Where electric light is used on the fixtures, the gas pipe

must not be used as part of the circuit. The connections are, however, essentially the same. All that is necessary is

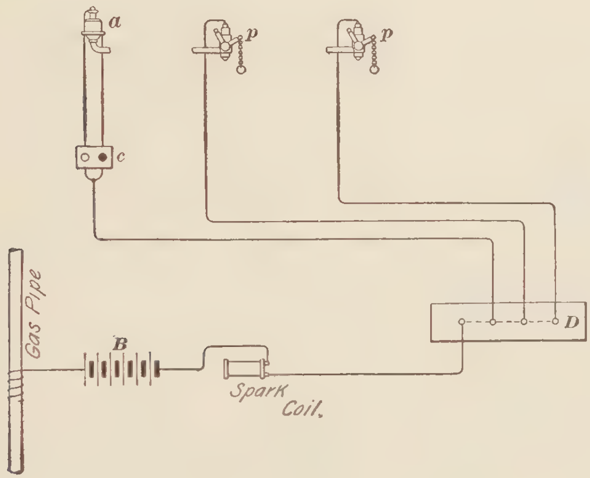


FIG. 34.

to use an additional wire instead of the pipe. The following Underwriters' rules relate to gas-lighting wiring in connection with electric-light fixtures.

Electric Gas Lighting.—

Where electric gas lighting is to be used on the same fixture with the electric light:

a. No part of the gas piping or fixture shall be in electric connection with the gas-lighting circuit.

b. The wires used with the fixtures must have a non-inflammable insulation, or, where concealed between the pipe and shell of the fixture, the insulation must be such as required for fixture wiring for the electric light.

c. The whole installation must test free from "grounds."

d. The two installations must test perfectly free from connection with each other.

67. Since the battery is momentarily short-circuited every time a spark is obtained, it would soon run down if the contacts on the burner were to remain permanently touching. To give notice of this, a **relay** (Fig. 35) may be used in series with the battery, the current entering at *b* and passing out at *c*, after circulating around the coil. The magnetic circuit is completed by an armature *a*, which is held back against a stop by the weight *w* when no current

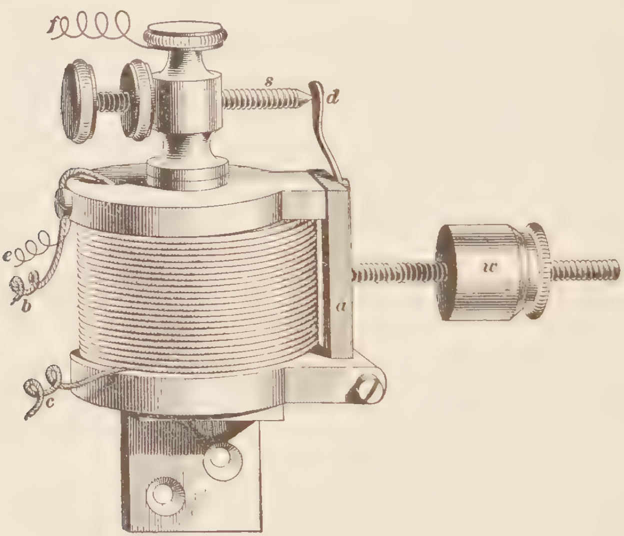


FIG. 35.

is passing. If a short circuit occurs, the armature is attracted, and the spring *d* is pressed against the platinum-tipped screw *s*, completing a local circuit by means of the wires *e*, *f* through a vibrating bell and one-cell battery. The current used in lighting the gas at a burner is of such short duration that the bell is not rung. A modification of this arrangement is to provide an armature on the spark coil itself, which shall close a local alarm circuit when the battery is short-circuited.

APPARATUS FOR MULTIPLE-LIGHTING SYSTEM.

68. The **multiple,** or **flash, system** of gas lighting is used in large halls where many lights are installed in groups. A fixed spark gap is used at each burner, both of the points being insulated from each other and from the gas pipe, except the last point of a series, which is grounded. The style of burner used is shown in Fig. 36, in which *a* and *b* are the points of the spark gap. To complete the connection between consecutive burners, a fine, bare copper wire, about No. 26 gauge, is stretched across, being secured through the small holes at the lower ends of the strips *a*, *b*. The body of the burner is made of some insulating substance, and a flange of mica *m* is added to give further protection. Since one circuit may consist of a large number of burners, it will be seen that the E. M. F. must be very high to force a current across so much air space, and to insure success, the wiring must be installed

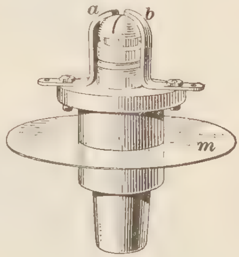


FIG. 36.

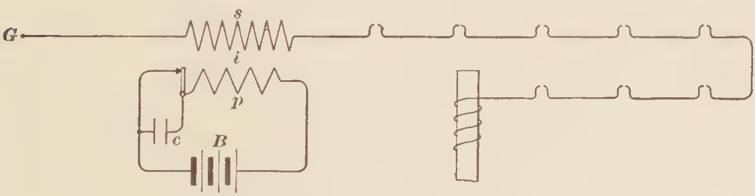


FIG. 37.

with the greatest precaution. The wire should nowhere be nearer to the gas pipe than $1\frac{1}{4}$ inches; if, however, it is necessary to approach more closely, the wire should be enclosed in glass tubing.

The apparatus required for this system of gas lighting consists of an induction coil *i*, Fig. 37, operated by a battery *B* and used with a condenser *c* across the spark gap of the primary *p*. The condenser cuts down the spark at the

circuit-breaker, for this spark would be very destructive in the case of a large coil. The fine-wire secondary *s* is grounded at *G*, and the other terminal is connected to the line wire passing to the burners.

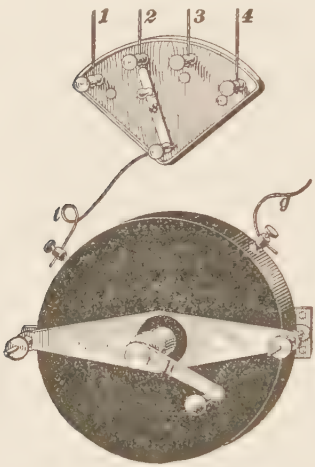


FIG. 38.

69. Frictional machines are also used in the multiple-lighting system. These generate static electricity, and in many cases are more reliable than induction coils, as there is no battery to get out of order. One form of this machine is shown in Fig. 38. One of the terminals *l* is to be connected to the switch handle *s* and the other *g* to ground. The machine is rotated by means of the handle *h*, and the switch is moved from one contact to the next, lighting the gas on each circuit *1*, *2*, *3*, *4* in rapid succession.

A SERIES

OF

QUESTIONS AND EXAMPLES

RELATING TO THE SUBJECTS
TREATED OF IN THIS VOLUME.

It will be noticed that the Examination Questions that follow have been divided into sections, which have been given the same numbers as the Instruction Papers to which they refer. No attempt should be made to answer any of the questions or to solve any of the examples until that portion of the text having the same section number as the section in which the questions or examples occur has been carefully studied.

ELECTRIC RAILWAYS.

(PART 1.)

EXAMINATION QUESTIONS.

(1) Name five systems that may be used for supplying current to street-car motors.

(2) What has limited the voltage for surface street-railway purposes to about 500 volts ?

(3) In the open-conduit or slot system, why are the conductor rails divided into sections, each section being supplied by its own feeder that runs back to the power house ?

(4) What things, besides the load center, must be considered in most economically locating a power house ?

(5) In what way is the alternating current used in street-railway work in the United States ?

(6) About what is the limiting distance from the power house to which it is profitable to run cars with the 500-volt direct-current system, and why ?

(7) With respect to a street-car system, where should the power house be located, provided the land can be obtained and other conditions do not interfere ?

(8) (*a*) Why is it not economical to have a large number of small units (engines and dynamos) in a railway power

house? (*b*) Why are units of the same size and type preferable to a variety of sizes and types?

(9) Why are direct-connected engines and dynamos, in spite of their greater first cost, preferred to belted machines?

(10) In street-railway stations, why should the engines, flywheels, and generators be of unusually substantial construction?

(11) (*a*) What is an overcompounded generator? (*b*) What is meant by the statement that a 500-volt generator is 20 per cent. overcompounded?

(12) Of what two or three kinds of panels does a modern railway switchboard generally consist?

(13) When the power for operating street-car motors is originally generated as a high-pressure alternating current of, say, 11,000 volts, state the various transformations through which the current passes before it reaches the car motors.

(14) Give two reasons why compound-wound generators are used in street-railway power houses.

(15) How should the shunt-field switch of a railway generator be arranged so as to cut off the current from the shunt field without any danger of the discharge current puncturing the insulation of the field spools?

(16) Explain the construction and the action of a Thomson astatic ammeter.

(17) (*a*) How is the total-output panel of a typical railway switchboard generally equipped? (*b*) How is a feeder panel equipped?

(18) What are the essential requirements of a good circuit-breaker?

(19) What is the object of the multiplying resistance in the field rheostat of the General Electric Company?

(20) With what apparatus is a generator panel of a typical railway switchboard usually equipped?

(21) (*a*) What is the distinctive feature of the General Electric circuit-breaker? (*b*) What is the distinctive feature of the Westinghouse and Cutter circuit-breakers?

(22) Suppose that in Fig. 10, W represents the center of a load of 200 kilowatts, W'' 100 kilowatts, and W' 300 kilowatts. Considering only the load, where should the power house for supplying the same be located, assuming the distances to be the same as given in Fig. 10? Illustrate your solution by means of a sketch.

(23) When should the shunt to the series field of a railway generator be finally adjusted, and why?

ELECTRIC RAILWAYS.

(PART 2.)

EXAMINATION QUESTIONS.

(1) Why cannot the output of a railway power station in watt-hours be accurately computed by multiplying together the average readings of the voltmeter and ammeter, taken at regular intervals, and the time in hours that the station is in operation?

(2) Why are boosters used in connection with storage batteries that are used to help the generators during intervals of heavy load?

(3) If generators that have formerly worked together successfully in parallel fail at any time to work together as they should, where would you look for the trouble?

(4) Why is the ordinary style of recording wattmeter not suitable for use in testing cars?

(5) (*a*) How is the arc extinguished in the General Electric lightning arrester for street-railway circuits? (*b*) How is the arc extinguished in one type of Westinghouse lightning arrester used for the same purpose?

(6) Why should the ammeter and circuit-breaker not be connected in that side of a compound-wound generator circuit to which the equalizer is connected?

(7) What is a tank lightning arrester and what is its chief advantage?

(8) If a car with passengers weighs 12 tons and it is desired to propel it up a 5-per-cent. grade at a speed of 8 miles per hour, what horsepower must be delivered to the motors, assuming that the efficiency between the trolley and wheels is 75 per cent.?

(9) Explain the auxiliary bus-bar method of supplying certain feeders with higher voltage than that of the regular station bus-bars.

(10) What two mistakes may be made in connecting a simple engine-driven series booster in the circuit, and how may they be corrected?

(11) When storage batteries are connected in a feeder circuit near the end of the feeder, why do they discharge when the load is above normal and charge when the load is below normal?

(12) What kind of a machine is a booster and how is it connected in a circuit for raising the voltage for certain feeders? Explain why it raises the voltage as the load increases.

(13) Explain how a series booster may be rendered inactive or cut out of the circuit.

(14) If it takes .128 ampere at 500 volts to push a 1-ton car at the rate of 1 mile per hour on a level, (*a*) how many amperes will it take, approximately, to propel a 20-ton car at the rate of 8 miles an hour on a level? (*b*) How many amperes will it take, approximately, to propel the 20-ton car up a 15-per-cent. grade at the rate of 6 miles an hour?

(15) What is a convertible booster?

(16) (*a*) For what purpose are storage batteries most used in street-railway work? (*b*) Why are they so advantageous for this purpose?

(17) What force will be required to move a 12-ton car on a level?

(18) What force will be required to start a 12-ton car on a 6-per-cent. grade ?

(19) What will be the limiting grade up which a car will start if $\frac{3}{4}$ of the total weight is on the drivers and the adhesive force is $\frac{1}{5}$ of this weight ?

(20) (*a*) What is the most common method of suspending trolley wires in the United States ? (*b*) What are its advantages over other methods ?

(21) Where can the center trolley-pole construction be used to good advantage ?

ELECTRIC RAILWAYS.

(PART 3.)

EXAMINATION QUESTIONS.

(1) What will be the resistance of the track circuit of a double-track road 2 miles in length if the 60-foot, 80-pound rails used are connected together with one No. 0000 copper bond wire 1 foot in length and if the contact resistance between each rail and bond wire is .0002 ohm?

Ans. .0394 ohm.

(2) In the preceding question, how many kilowatt-hours will be wasted in one year of 365 days in the track circuit if the average current for 20 hours each day is 500 amperes, the road being shut down the remaining 4 hours each day?

Ans. 71,905 kilowatt-hours.

. (3) In question 1, how many kilowatts will be saved if two No. 0000 copper bonds are used at each rail joint instead of one only? Ans. 2.475 kilowatts.

(4) (*a*) On an overhead-trolley system, why are anchor wires used? (*b*) Why are turnbuckles used?

(5) (*a*) Into what three divisions may the electrical equipment of ground-return trolley roads be divided? (*b*) Which part requires the most copper?

(6) What are strain insulators, and where used?

(7) What is the usual height of the trolley wire above the rail where there are no interfering conditions?

(8) What is the cross-sectional area of a 70-pound rail?

(9) How would you find the proper position for an overhead-trolley frog where a branch line meets a main line?

(10) What would be the resistance of 1 yard of a 70-pound steel rail?

(11) What would be the resistance of 1 yard of a steel rail having a cross-sectional area of 6 square inches?

(12) What are the main requirements for line devices on overhead-trolley work?

(13) What is the resistance of 1,000 feet of 60-pound steel rails, not including joints?

(14) Why is it so difficult and why so necessary to keep the adjacent ends of rails electrically well bonded together?

(15) (*a*) How is an ordinary wire splice made? (*b*) How are trolley wires spliced?

(16) What is the resistance, not including joints, of 3 miles of double track laid with 80-pound rails?

(17) For what electric railways is the third rail more suitable than either the overhead-trolley or conduit systems?

(18) Why is a poorly constructed track so hard on the car?

(19) Why is it a good plan to have two bonds around each rail joint?

(20) (*a*) What two kinds of rails are in general use for electric railways? (*b*) Where is each kind used most?

(21) What are the relative advantages and disadvantages of the cast-welded and electrically welded joints?

(22) (*a*) What are the two kinds of girder rails? (*b*) What are the advantages and disadvantages of the grooved rail?

(23) (*a*) What is used in recently constructed roads for the so-called third rail? (*b*) Where may the third rail be placed?

ELECTRIC RAILWAYS.

(PART 4.)

EXAMINATION QUESTIONS.

(1) Suppose we have a single-track trolley road 3 miles long fed from a power station at one end, as shown in Fig. I. There are ten cars, requiring on an average a current of 24 amperes per car. If the trolley wire is No. 00 and the track resistance, including bonds, is .0111 ohm per

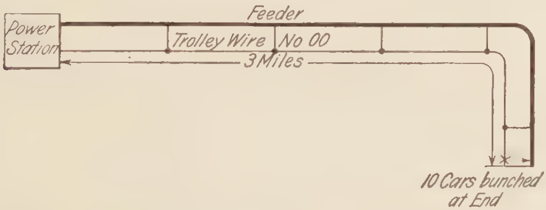


FIG. I.

1,000 feet of single track (two lines of rails), what must be the size of the feeder in order that the drop shall not exceed 110 volts, even if the total load is concentrated at the end of the road most distant from the power house? Assume the trolley wire to have the same conductivity as the soft-copper feeder. Ans. 472,475 cir. mils.

(2) What is the relation between the drop on a given line for the same total number of amperes with the load

evenly distributed and with it all concentrated at the distant end of the line?

(3) After having properly calculated the size feeder required to carry a given current with a given drop, what other property of the wire is it necessary to bear in mind?

(4) A trolley road fed from a power station located at the middle, as shown in Fig. II, has a double track 4 miles long and twelve cars, requiring on an average a current of 25 amperes per car. If the trolley wire is No. 00, and we assume that it has the same conductivity as the soft-copper

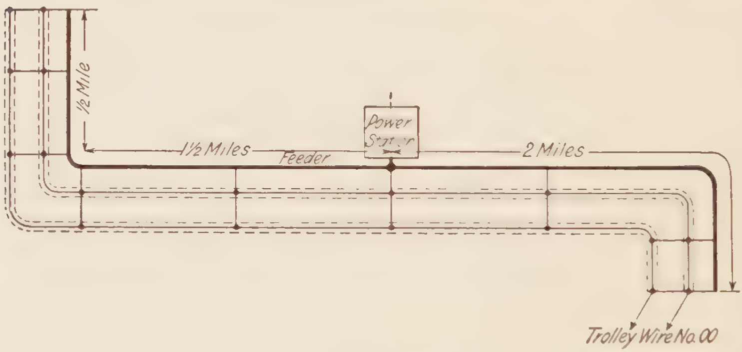


FIG. II.

feeder, and the track resistance, including bonds, is .0056 ohm per 1,000 feet of double track, what must be the size of the feeder in order that the drop shall not exceed 100 volts even if all the cars are concentrated at one end of the road? Ans. 149,728 cir. mils.

(5) What are some of the results of operating street cars on too low a voltage?

(6) (*a*) Why must not the tread of a car wheel be ground down too much? (*b*) How can one tell whether or not a flat can be advantageously removed by grinding the tread of a wheel?

(7) What is meant by electrolysis in electric-railway work?

(8) What points on underground-cable sheaths, water pipes, etc. are liable to injury by electrolysis?

(9) What are the advantages and disadvantages of operating cars on the three-wire system?

(10) Fig. III shows the layout of a single-track road operating twelve cars, each car requiring an average current of 25 amperes. The road is divided into three sections by means of line breakers, each section being provided with a No. 00 main having a cross-section of approximately 133,000 circular mils and a resistance of about .08 ohm per

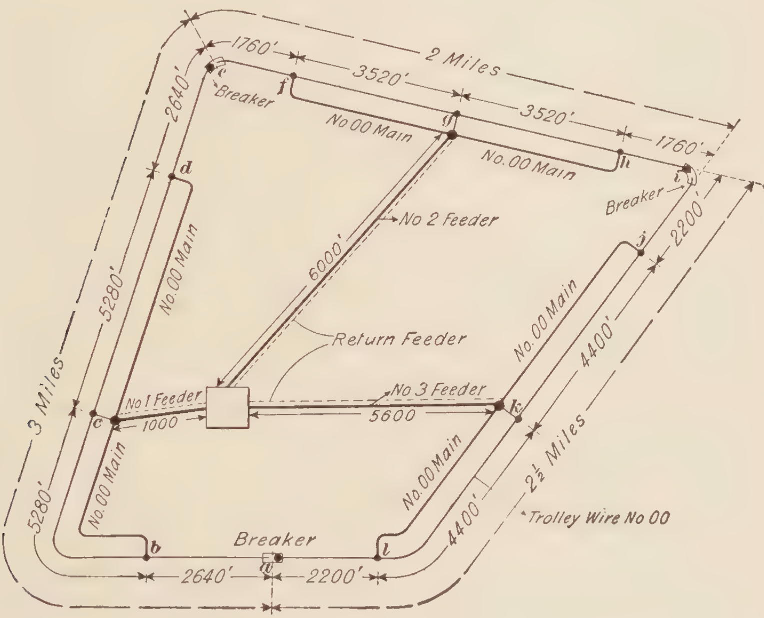


FIG. III.

1,000 feet, including joints, etc. The mains are fed by the feeders *1*, *2*, and *3*. Feeders running parallel to those for the overhead system and of the same size are to be used for connecting the track circuit to the power station. The trolley wire is No. 00, having a resistance of about .08 ohm per 1,000 feet and a cross-sectional area of approximately

133,000 circular mils. Calculate the size of feeders required in order that the drop at any one of the cars, if they are all in the positions shown by the small, round dots, shall not exceed 50 volts. Wherever convenient, formula **3** is to be used in the computations.

Ans. { Feeder *1*, 75,604 cir. mils.
Feeder *2*, 362,923 cir. mils.
Feeder *3*, 376,400 cir. mils. }

(11) (*a*) Calculate the drop at the car at *a* in Fig. III, assuming that No. 00 wire, whether trolley wire or main, has a resistance of .08 ohm per 1,000 feet and that a single track, including bonds, has a resistance of .0111 ohm per 1,000 feet, and that the No. *3* feeders have a cross-section of 376,400 circular mils. In this case do not use formula **3.** (*b*) What is the difference in the volts drop between this more exact result and that allowed the same car in the preceding problem?

Ans. { (*a*) 48.39 volts.
(*b*) 1.61 volts. }

(12) What is the principal reason for connecting the positive pole of the dynamo to the trolley side of the line?

(13) What trolley systems do not cause any electrolysis in neighboring underground pipes or conductors?

(14) What machines are necessary for an average machine shop for a fairly large road?

(15) What are flats on car wheels and how are they removed?

(16) On what does the amount of damage due to electrolysis depend?

(17) If it is found that the drop on a certain section of a road is larger than it should be, what should be done before proceeding to spend money for additional overhead feeders or in improving the track circuit?

(18) For what purposes may air compressors and reservoirs be profitably used in car repair shops?

(19) What methods should be used to prevent the injury of cable sheaths, water pipes, etc. by electrolysis?

(20) What precautions against fire should be taken in car barns?

(21) (*a*) How much pit room would be required for inspecting and repairing 200 cars that are housed at one car barn? (*b*) What should be the depth and length of the shortest pit?

ELECTRIC RAILWAYS.

(PART 5.)

EXAMINATION QUESTIONS.

(1) Where on a car are the starting rheostat, the lightning arrester, and the fuse box generally placed?

(2) (*a*) What is meant by the rheostatic method of control? (*b*) What is the most important objection to this method?

(3) What is an ordinary double truck and what is a maximum-traction truck? Point out the essential difference in their construction.

(4) (*a*) For what kind of traffic are long double-truck cars especially suitable, and why? (*b*) For what kind of traffic are long double-truck closed cars not suitable, and why?

(5) (*a*) Why are rheostats used in starting car motors? (*b*) What would happen if the controller handle were left on a notch that would leave the starting coil in the circuit for a long time?

(6) For what purpose is a single-truck car superior to either the maximum or ordinary double-truck car with two motors only?

(7) For what classes of work is the rheostatic method of controlling motor speed used quite extensively?

(8) (*a*) What is the difference between the K10 and K11 controllers? (*b*) For what purpose is the K10 controller used and what are some of its advantages over the K2 controller?

(9) What is the full-field control method of regulating the speed of street-car motors?

(10) If the gear ratio of a single-reduction car motor is 4.8 and the gear on the armature shaft has 15 teeth, how many teeth are there on the axle gear? Ans. 72 teeth.

(11) (*a*) What is the series-parallel method for controlling street cars? (*b*) State one advantage of the series-parallel method.

(12) What is the shunt method of controlling street-car motors?

(13) What will happen if one field coil in a four-pole motor is connected incorrectly?

(14) What is the object of the two motor-cut-out switches in the bottom of the K2 controller?

(15) For what purpose is the blow-out coil used on a controller?

(16) What is the usual method of controlling the speed of cars having a four-motor equipment?

(17) What is the difference between the K2 and K11 controllers?

(18) What is the use of the interlocking device on a car controller?

(19) Why are not ordinary street-car motors directly connected to the car-wheel axles?

(20) How should the four field coils of a street-car motor be connected?

(21) In Fig. 30 (connections for K10 controller), trace the path of the current when the No. 2 controller is on the eighth notch and the reverse switch at the "ahead" position.

(22) Make a sketch showing the various combinations effected by the K2 controller.

(23) In Fig. 38 (connections for Westinghouse controller), trace the path of the current when the controller is on the last notch and the reverse switch in the position shown in the figure.

(24) In Fig. 42 (connections for four-motor equipment), trace the path of the current when the right-hand controller is on the last notch.

(25) In Fig. 27 (connections for K2 controller), trace the path of the current on the first notch when the No. 1 controller is in use and the left-hand cut-out switch in the No. 1 controller is thrown up.

(26) Wherein does the Westinghouse 28A controller differ from the K2 or K10 controllers as regards the method of reversing the motors?

(27) How would you connect a 99-coil armature for a field with its pole pieces on the diagonal?

(28) How would you connect an armature for a field with pole pieces on the diagonal, if the armature has 93 coils and 47 slots?

ELECTRIC RAILWAYS.

(PART 6.)

EXAMINATION QUESTIONS.

(1) (*a*) What is apt to happen if the pressure of the trolley wheel against the trolley wire is too light or too heavy? (*b*) What is about the proper pressure under ordinary conditions?

(2) Why is the lamp circuit in a car tapped to the trolley circuit ahead of both hood switches?

(3) What is the object of the canopy switch?

(4) Make a sketch showing the connections for a changeable headlight on a car with a single lamp circuit.

(5) What inspections should be made of lightning arresters after a thunder storm?

(6) Give some of the main features of double-truck brake riggings.

(7) What are the main features that should govern the selection of a trolley harp?

(8) In the General Electric canopy switch, what provision is made to extinguish the arc when the switch is opened?

(9) (*a*) For what purpose is the governor of an air brake used? (*b*) Describe the action of the Christensen governor.

(10) For what purpose is the multiple-unit system intended ?

(11) Why are electric car heaters used in spite of the fact that it costs more to operate them than to heat the car by stoves ?

(12) Describe the Westinghouse canopy switch and point out the means by which the arc is suppressed.

(13) What size of copper fuses are used for 30-horsepower and 50-horsepower equipments ?

(14) In the multiple-unit car system, what constitutes (*a*) a single unit ? (*b*) a multiple-unit train ?

(15) How are the two coils or circuits and the switch of car heaters arranged so that three different degrees of heat may be obtained ?

(16) (*a*) State some of the advantages of street-car circuit-breakers over fuses. (*b*) Describe briefly one form of circuit-breaker and show how the arc is extinguished.

(17) What two troubles may occur through the incorrect connecting of car heaters ?

(18) (*a*) What two classes of air brakes are used on street cars ? (*b*) For what systems or class of cars is each most suitable ?

(19) Explain briefly the principle of the straight air brake.

(20) What is the principle on which an electric-car brake works and why must hand-brakes be used in connection with an electric brake in order to hold a car on a grade ?

(21) (*a*) In order to avoid braking the wheels so tight as to make them slide on the rail, what must be the relation between the weight on the wheel and the pressure applied to the brake shoe ? (*b*) When bringing a high-speed car to a stop, why should the brake be released somewhat as the speed decreases ?

(22) What is the principal difference between the General Electric and Westinghouse electric brakes?

(23) At what two places is trouble in a lamp circuit most likely to occur?

(24) (*a*) In how many different positions may the brake or engineer's valve of the Christensen air brake be placed? (*b*) What is the name given to each position?

(25) Why are lamps in cars connected five in a series between the ground and the trolley?

(26) Make a sketch of the connections for the General Electric lightning arrester used on cars.

INTERIOR WIRING.

(PART 1.)

EXAMINATION QUESTIONS.

(1) In wiring a building for incandescent lamps, why is it important to have the drop in the various circuits limited to a small amount?

(2) (*a*) For what class of work is "slow-burning" weather-proof wire allowable? (*b*) How must this wire be supported?

(3) Where do the Underwriters' rules require automatic cut-outs (fuses or circuit-breakers) to be placed?

(4) (*a*) Why is it poor economy to burn incandescent lamps after they have become dim? (*b*) What is the effect of burning lamps above their normal voltage?

(5) How would you calculate the sizes of wire required for house wiring on the three-wire 110–220-volt system?

(6) Current is supplied to 120 16-candlepower 110-volt incandescent lamps on the three-phase system. What will be the current in each of the three wires if each lamp requires $\frac{1}{2}$ ampere? Ans. 34.6 amperes.

(7) (*a*) About how many watts per candlepower does an ordinary incandescent lamp take? (*b*) A 32-candlepower

lamp requires 4 watts per candle and is operated in a 110-volt circuit; what current will the lamp take?

Ans. (*b*) 1.16 amperes.

(8) (*a*) For what are cut-outs used? (*b*) How are they usually constructed?

(9) If 500 16-candlepower lamps, each taking ½ ampere, are to be supplied by a 110-volt, four-wire, two-phase system, what will be the current in each line wire?

Ans. 125 amperes.

(10) What are the Underwriters' requirements relating to joints for wires used in connection with interior wiring?

(11) Point out some of the differences between open- and enclosed-arc lamps.

(12) A pair of feeders are to be installed in a factory building to carry current for 500 16-candlepower 110-volt lamps from the dynamo room to a center of distribution situated in another building; the total distance (one way) from the dynamo room to the center of distribution is 400 feet and the drop is to be limited to 5 volts. (*a*) What size wire will be required? (*b*) What size wire would be required if the carrying capacity alone were considered? Assume that weather-proof wire is used.

(13) Is the carrying capacity of rubber-covered wire as given by the Underwriters as large as that of weather-proof wire; if not, why?

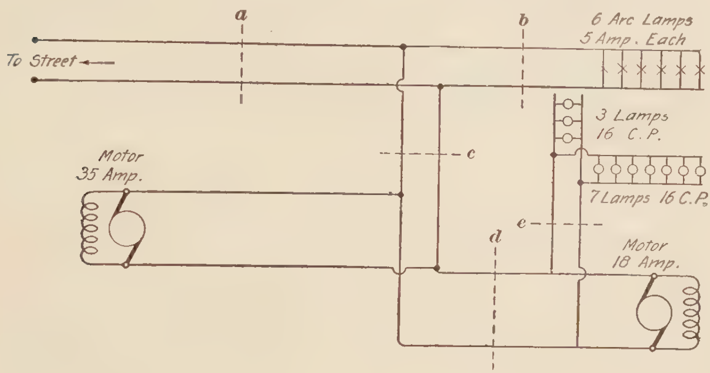
(14) Why is it not necessary to use large wires in order to avoid a drop when connecting constant-potential arc lamps?

(15) (*a*) Are the odd sizes of wire between Nos. 7 and 14 used for interior wiring, and if not, why? (*b*) What is a mil?

(16) In laying out the branch circuits, what determines the number of lamps to be allowed on any one circuit?

(17) Into what three general classes may fires caused by defective wiring be divided?

(18) The illustration shows a wiring plan of a network that supplies current to 110-volt lamps and motors as indicated. (*a*) Make a sketch and indicate the current flowing at *a*, *b*, *c*, *d*, and *e*. (*b*) Mark the sizes of wire necessary for the



various parts of the system in accordance with the Underwriters' requirements, assuming that rubber-covered wire is used. (*c*) Show where main cut-outs or branch blocks would be required and the size of fuses to be used in order to protect the wire.

(19) What are the four most important things to be considered when installing a job of wiring?

(20) What is the effect of supplying a system designed for high voltage, say 104 volts, with low voltage, say 52 volts?

(21) When may single-pole switches be used in an interior wiring installation?

(22) (*a*) What is the smallest size of wire allowable for interior-wiring work outside of fixture wiring? (*b*) If no requirements must be met in regard to line drop, what determines the minimum sizes of wire to be used for a given installation?

(23) Into what two classes of circuits may house wiring usually be divided?

(24) (*a*) What is the principal advantage of the three-wire system? (*b*) What are some of the disadvantages of the three-wire system?

(25) Why should the two sides of a circuit always be run in the same conduit when alternating current is used?

(26) (*a*) Why should unprotected wires never be laid in plaster? (*b*) Why should electric-light wires never be fastened with staples?

INTERIOR WIRING.

(PART 2.)

EXAMINATION QUESTIONS.

(1) By the aid of Table I determine the size of wire that would be required for a line (2 wires) extending a distance of 120 feet and carrying 30 amperes with a drop not exceeding 3 volts. Ans. No. 6 B. & S.

(2) Find the area in circular mils of a round wire $\frac{1}{8}$ inch in diameter.

(3) After a building has been wired, what tests should be made?

(4) (*a*) What tests and observations does the Underwriters' inspector usually make? (*b*) When should concealed work be inspected by the Underwriters' inspector?

(5) What instrument is generally used in testing out connections, and also in testing for grounds and crosses?

(6) What size B. & S. copper wire should be used, allowing a drop of 2 volts, to supply a group of 80 110-volt 16-candlepower incandescent lamps at a distance (one way) of 200 feet? Each lamp requires $\frac{1}{2}$ ampere.

Ans. No. 1 B. & S.

(7) What is the diameter of a wire having a cross-sectional area of 10,816 circular mils? Ans. .104 in.

(8) What will be the current in the outside wires of an evenly balanced three-wire system supplying 60 lamps if

each lamp requires 52 watts? There is a drop of 2 volts in each outside wire to load center, and the pressure between the outside wires at the center of distribution is 220 volts.

(9) Determine, by means of Table II, what size of wire would be required to transmit 30 amperes a distance of 120 feet (one way) with a line drop not exceeding 3 volts.
Ans. No. 6 B. & S.

(10) Calculate the size of wire necessary to supply 50 16-candlepower 110-volt lamps located in a group at a distance of 150 feet (one way) from the center of distribution, allowing a drop not to exceed 2 volts. Ans. No. 4 B. & S.

(11) In a building already wired, the drop in a certain feeder, extending a distance of 100 feet (one way), is excessive. The feeder, which consists of a No. 6 wire, carries 40 amperes. What size of wire should be connected in parallel with the No. 6 wire so as to reduce the drop to 2 volts?
Ans. No. 8 B. & S.

(12) What are the Underwriters' requirements (*a*) about supporting wires in damp places? (*b*) about the use of fuse blocks and rosettes in damp places?

(13) (*a*) Where may wooden molding for wires be used? (*b*) Where must it not be used?

(14) What two important conditions require additional precautions for ship wiring?

(15) (*a*) What appliances do the Underwriters require to be placed at a convenient point near where the wires enter a building in addition to the meter that is usually installed? (*b*) In what order should these appliances be placed?

(16) Make a sketch showing how a lamp or group of lamps may be controlled independently from two different points.

(17) Why should good metallic connections be made between all metal conduit pipes, outlet boxes, etc. and the ground?

(18) (*a*) Why is the flexible armored conduit not so good as the iron-covered conduit? (*b*) What kinds of conduits for concealed wiring are now approved by the Underwriters?

(19) What is the so-called loop system of wiring?

(20) What must be done when the size of wire is changed at a junction box?

(21) Where wires are brought through the wall to outlets or cut-outs, what precautions must be taken?

(22) How must wires be supported in concealed knob-and-tube work?

(23) Why will two wires (*a*) safely carry more current than one wire of equivalent cross-section and (*b*) give the same drop with the same total current?

(24) A wireman having at hand only some No. 14 wire desires to run a line a distance of 100 feet to supply 50 16-candlepower lamps requiring $\frac{1}{2}$ ampere each. How many No. 14 wires must be run in multiple in order to have a drop of about 3 volts?

Ans. Four No. 14 wires on each side of the circuit.

(25) In damp places (*a*) what kind of sockets must be used and (*b*) how should they be put up?

(26) (*a*) Where may single-pole switches be used? (*b*) Why are they used when possible in preference to double-pole switches?

(27) Why is it that No. 14 wire is generally used for lamp circuits in all ordinary dwelling houses?

INTERIOR WIRING.

(PART 3.)

EXAMINATION QUESTIONS.

(1) Where it is necessary to install wires very cheaply for temporary or occasional use and for some special purpose, such as the illumination of the entire outside of a building, what are the important items to be kept in view and what are not so important?

(2) What are considered as high-potential circuits?

(3) On what does the ratio of the electromotive force at the terminals of the primary and secondary winding of a transformer depend?

(4) Why cannot the same protective devices be used on constant-current as on constant-potential circuits?

(5) What sort of switches must be used for constant-current systems?

(6) (*a*) What is a self-restoring annunciator? (*b*) What are its advantages?

(7) To what class of work is the use of high-potential direct current almost exclusively confined in the United States?

(8) Why do the Underwriters' rules prohibit the operation of motors or lights from street-railway circuits, except on street cars, or in car barns, or railway power houses?

(9) State two particulars in which the wiring for constant-current arc lamps differs from that for other open work.

(10) (*a*) How must a motor and starting resistance box be protected? (*b*) When may single-pole switches be used with motors?

(11) Why is it bad practice to bring the wires of high-voltage systems inside a building?

(12) When the frame of a high-potential machine cannot be insulated from the ground, what should be done?

(13) (*a*) Name two kinds of stage dimmers. (*b*) With what current systems may each be used?

(14) Is it allowable to use the gas pipe as part of the electric gas-lighting circuit on fixtures wired for electric light?

(15) What is the greatest danger to be feared in the use of transformers?

(16) What kind of wire is the best to use for bell and annunciator work when it is exposed to considerable moisture?

(17) What is said in the Underwriters' rules concerning the use of circuit-breakers, automatic starting boxes, and automatic underload switches?

(18) What are the ordinary requirements connected with the installation of transformers?

(19) (*a*) Of what does the most common form of theater dimmer consist? (*b*) How is it connected in the circuit?

(20) If metal staples are used to fasten down bell and annunciator wires, what precautions should be taken?

(21) When incandescent lamps are connected in series in a circuit, state at least two of the Underwriters' rules concerning such work.

(22) In series gas-lighting systems, why is it necessary to insulate the wires very carefully?

(23) What precautions must be taken when wiring motors?

A KEY

TO ALL THE

QUESTIONS AND EXAMPLES

CONTAINED IN THE

EXAMINATION QUESTIONS

INCLUDED IN THIS VOLUME.

The Keys that follow have been divided into sections corresponding to the Examination Questions to which they refer, and have been given corresponding section numbers. The answers and solutions have been numbered to correspond with the questions. When the answer to a question involves a repetition of statements given in the Instruction Paper, the reader has been referred to a numbered article, the reading of which will enable him to answer the question himself.

To be of the greatest benefit, the Keys should be used sparingly. They should be used much in the same manner as a pupil would go to a teacher for instruction with regard to answering some example he was unable to solve. If used in this manner, the Keys will be of great help and assistance to the student, and will be a source of encouragement to him in studying the various papers composing the course.

ELECTRIC RAILWAYS.

(PART 1.)

---

(1) The overhead-trolley system, the open-conduit or slot system, the electromagnetic or closed-conduit system, the third-rail system, and the system in which storage batteries are carried on each car. See Art. **2.**

(2) The fact that a higher voltage is not only harder to insulate, but is very dangerous to life. See Art. **14.**

(3) This cuts the road into distinct sections, so that trouble on one section may not interfere with the running of cars on other sections. Moreover, since each feeder, which supplies only one section, has its own switch and circuit-breaker, the attendant in charge at the power house can tell, when a circuit-breaker flies out on account of a ground, on exactly what section or stretch of track the trouble is. Furthermore, in case of a block on the road, the simultaneous efforts of all the motormen to start their cars will not cause serious overloads at the power house, because the switchboard attendant has every section of the road under his control and can therefore compel the cars to start up, one section at a time. See Art. **7.**

(4) The facility for getting coal into the power house at small expense, the quality and cost of water for the boilers and condensers, and also the cost of the land for the power house. See Art. **18.**

(5) Alternating current is generated at a large power house that is economically located with regard to coal and

water supply. The current is generated at a high pressure and is transmitted to some point centrally located, with respect to the street-car load or traffic, where the high-pressure alternating current is transformed into direct current at about 550 volts by means of static transformers and rotary converters. If the distances are very long, it may be necessary to step up the pressure at the station by means of transformers. See Arts. **35** and **48.**.

(6) About 7 miles; because, in order to keep the line loss down to a reasonable amount, the feeders for a longer distance system would be so large that their cost would become excessive. See Art. **17.**

(7) It should be located at the center of the load, which corresponds to the center of gravity of a system of bodies. This location may or may not be at the geographical center of the track system. See Art. **16.**

(8) See Arts. **26** and **39.**

(9) Because the saving in space, absence of belts, and perhaps a slightly better efficiency make up for the increased first cost. See Art. **24.**

(10) Because the load is liable to very severe fluctuations that subject the machinery to very severe strains. See Art. **25.**

(11) (*a*) An overcompounded generator is one at whose terminals the voltage rises as the load increases, so as to keep the voltage constant at some point on the line in spite of the increased drop in the machine itself and in the line. See Art. **41.**

(*b*) It means that the voltage, which is 500 at the terminals of the generator on open circuit, increases as the load increases, until at full load the voltage at the terminals of the generator is 20 per cent. greater, or 600 volts. See Art. **41.**

(12) Generator panels and feeder panels. A total-output panel is also provided in some cases. See Art. **54.**

(13) The current that is generated at a pressure of 11,000 volts passes through the high-tension cables to a substation, where it is reduced in pressure by means of static transformers. This lower pressure alternating current is then transformed, by passing it through a rotary converter, into direct current at about 600 volts. It is then transmitted to the car motors. See Art. **48.**

(14) First, because compound-wound generators will operate in parallel if properly installed, and second, because they have the valuable property of automatically holding the voltage constant or even increasing it as the load increases. See Art. **40.**

(15) It should be so arranged as to connect a resistance across the shunt-field terminals before the shunt-field circuit is opened. This allows the field to discharge through the resistance and avoids the danger of puncturing the insulation. See Art. **61.**

(16) Electromagnets having high-resistance exciting coils connected directly across the circuit are used to furnish a magnetic field in which the moving coils, mounted on an aluminum disk, can rotate. The moving coils are supplied with current by being connected across the terminals of an ordinary ammeter shunt that is connected directly in the circuit the current in which is to be measured. The retarding force acting on the rotating disk and coils is the attraction of the field magnets for small iron vanes fixed to the moving member. If the electromagnet becomes weaker for any reason, the force acting on the movable coils for a given current flowing through them becomes weaker, but the retarding force between the electromagnet and the iron vanes also decreases in the same proportion, so that the reading of the ammeter is not affected. See Art. **67.**

(17) (*a*) The total-output panel is generally equipped with a voltmeter, a total-output ammeter, and a recording wattmeter.

(*b*) A feeder panel is equipped with a feeder switch, a circuit-breaker, and generally, though not always, with an

ammeter. The feeder panels are often equipped also with lightning arresters, usually mounted on the back of the panel. See Arts. **56** and **57.**

(18) It must be capable of opening the circuit an indefinite number of times at the current for which it is set, without injuriously burning and blistering any important part. This means that the arc produced when the circuit is finally opened must not occur at the main-switch contacts of the circuit-breaker, but at some other auxiliary contact points where it does no serious harm. Such auxiliary contacts should be between substances that can be easily and cheaply replaced when continued use has worn them away. In some breakers, the arcs between the auxiliary contacts are blown out instantly by an electromagnet connected in series with the auxiliary contacts. See Art. **68.**

(19) See Art. **63.**

(20) The following apparatus usually appears on the front of a generator panel: a main switch, voltmeter plug, field switch, pilot-lamp receptacle, field-rheostat handle, ammeter, circuit-breaker, and a small switch for controlling any station lights or motors that may be operated from the generator. On this panel there is also a lightning arrester, usually mounted on the back of the panel. See Fig. 19 and Arts. **55** and **58.**

(21) (*a*) The distinctive feature of the General Electric circuit-breaker is a magnetic blow-out device that extinguishes the arc between the auxiliary contacts. See Art. **69.**

(*b*) The distinguishing features of the Westinghouse and Cutter circuit-breakers are their simplicity and the auxiliary carbon contacts between which the arc is suddenly broken. See Arts. **71** and **72.**

(22) The center of gravity between W and W'' will be at a distance l from W such that $l \times W = (L - l)\ W''$. Substituting the proper values for W, L, and W'' in this equation gives $l \times 200 = (7 - l)\ 100$; simplifying, we get $200 \times l$

$= 700 - 100 \times l$, which gives $l = \frac{700}{300} = 2\frac{1}{3}$ miles. Hence, a load of 300 kilowatts, which we will call W''', $2\frac{1}{3}$ miles from W may be represented as equivalent to both W and W''. Since W' is also 300 kilowatts, then the center of gravity of W' and W''' will be half way between them. Hence, the best position for the power house, for the three loads, is at this center point, which is half way between W' and a point on the line joining W and W'', just $2\frac{1}{3}$ miles from W. See Art. **21.**

(23) The shunt should always receive its final adjustment after the dynamo becomes heated, because if adjusted for a certain amount of compounding while the machine is cold, it will fall short of this amount after it is hot, for two main reasons: First, the shunt field loses strength as it gets hot because its resistance increases, and hence the shunt-field current decreases; second, the series coils heat more than the shunt, because the latter being more exposed to the air has more of an opportunity to radiate its heat, and hence the series coils increase in resistance at a greater rate than the shunt. See Art. **45.**

ELECTRIC RAILWAYS.

(PART 2.)

---

(1) Because the variations in load are very violent and sudden and the average readings so obtained would not represent the correct average value of the volts and amperes. In order to get a correct average value of such a suddenly varying quantity as the current, it is necessary to obtain an average of all the instantaneous values; that is, readings would have to be taken at least as often as every second. It is impossible to obtain and write down such frequent readings from an ammeter, to say nothing of the tedious work it would require, and, moreover, instruments have been devised that will measure the output directly in watt-hours. See Art. **1.**

(2) The generators, being overcompounded, increase the voltage at the bus-bars as the load increases, but the storage batteries, on account of their internal resistance and their becoming discharged, would decrease in voltage as their output increases; hence, in order that the voltage of the storage-battery circuit shall not fall below that of the bus-bars when the load is heavy, a booster is necessary to raise the voltage of the storage-battery circuit. The booster is also used to help charge the storage battery when the load is light. See Art. **23.**

(3) It would indicate a fault of some kind in the equalizer connections; therefore, look for poor contacts at the

equalizer bus-bars or at other connections in the equalizer circuit. See Art. **4.**

(4) Because the shocks and jars would soon knock it out of adjustment, and, moreover, a stronger twisting action is necessary for a car meter, as the jarring would otherwise interfere with the accuracy of the meter. See Art. **3.**

(5) (*a*) In the General Electric lightning arrester for street-railway circuits, the arc is extinguished by a magnetic blow-out device.

(*b*) In one type of the Westinghouse lightning arrester, the arc is extinguished by smothering it in a confined space between two lignum-vitæ blocks, between which it is formed by the passage of the discharge to earth. See Art. **5.**

(6) Because if there is a current flowing in the equalizer, the current in the generator main to which the equalizer is connected will not have the same strength as the current generated in the machine, but the current in the other main of the machine will be the same, and hence this is the current that should be measured by the ammeter and limited by the circuit-breaker. See Art. **8.**

(7) It is a tank of water permanently connected to the ground and having in it a group of plates that may be temporarily connected, through switches, with the line circuit during lightning storms. Its great advantage is that it affords during a storm a constant path of comparatively low impedance without an air gap from the line to the ground. Hence, the induced charges, due to overhead charged clouds, can continually pass to earth as rapidly as they are created; thus, the condition is not favorable for induced charges to accumulate until great enough to produce a stroke and a disruptive discharge. See Art. **6.**

(8) The car will cover in 1 minute $\frac{8 \times 5,280}{60} = 704$ feet $= D$ (see formula **2**). On a 5-per-cent. grade, the vertical distance the car would rise in 1 minute $= 704 \times .05 = 35.2$ feet $= h$. The weight of the car expressed in pounds

$= 12 \times 2{,}000 = 24{,}000$ pounds $= w$. The force required to propel the car is, by formula **1,** $f = 25 \times 12 = 300$ pounds, and the efficiency being 75 per cent., $\mathsf{E} = .75$.

Then, by formula **2,** we have

$$H = \frac{h\,w + D\,f}{33{,}000\ \mathsf{E}} = \frac{35.2 \times 24{,}000 + 704 \times 300}{33{,}000 \times .75}$$
$$= 42.7 \text{ H. P. approx.} \quad \text{Ans.}$$

(9) An extra machine that generates a higher voltage than the regular machines is used, its positive terminal being connected to a separate auxiliary bus-bar. The feeders requiring this higher voltage are connected to this auxiliary bus-bar. See Fig. 6 and Art. **10.**

(10) The connections of the armature and field may be reversed with respect to one another so that the machine will not pick up or generate at all. This can be corrected by reversing the field and armature connections with relation to one another; or, the connections mentioned above may be correct, but the machine as a whole may be reversed in the circuit so that the polarity of the booster opposes that of the dynamo supplying the feeder. This may be corrected by reversing the connections of the positive and negative terminals of the booster to the feeder. See Art. **14.**

(11) When the load is heavy, the drop in the feeders to the storage battery and far end of the trolley wire is large; hence, the voltage at the end of the feeder due to the station generator is lower than normal and lower than that of the storage battery, and consequently the storage battery discharges, thus helping to carry the excessive load. On the other hand, when the load is light, the drop in the feeder is small; the voltage is therefore higher than normal and higher than that of the storage battery, consequently the storage battery is charged. See Art. **24.**

(12) The boosters commonly used for raising the voltage of certain feeders are series dynamos, and they are connected between the positive bus-bar of the station and the

feeders requiring the higher voltage. Since the entire current for certain feeders passes through the field coils of the booster, it follows that the strength of the booster field will increase with the load, that is, with the current; and if the speed of the armature is kept constant by the engine or motor driving it, then it follows that the E. M. F. generated will increase as the current passing through the booster increases. Hence, the voltage on certain feeders is boosted as the load in these feeders increases, and this voltage is practically independent of the load on the main bus-bars of the station. See Art. **12.**

(13) The booster may be rendered inactive by simply short-circuiting its field or by first short-circuiting the field and then short-circuiting the whole machine. In either case, it is theoretically immaterial whether the armature is allowed to run or not, but it is better to finally open the booster circuit. See Fig. 8 and Art. **15.**

(14) (*a*) It will require $.128 \times 20 \times 8 = 20.48$ amperes. Ans. See Art. **30.**

(*b*) It will require $.128 \times 20 \times 6 \times 15 = 230$ amperes. Ans. See Art. **31.**

(15) It is a regular railway generator that is connected by means of switches, so that it may either be thrown in series with a feeder, in order to act as a booster for that circuit, or be used as a regular generator. See Art. **17.**

(16) (*a*) They are used mostly to help the station carry the extreme loads on the lines during the busy parts of the day, that is, to take the peak of the load, as it is commonly expressed. They are also used to help carry heavy momentary loads.

(*b*) Because the batteries can be charged when the load is below the average and will discharge when the load is above the average, thus tending to keep the generators about fully loaded at all times; and, moreover, in large stations an excessive investment in generators is not then

required merely to take care of the occasional overloads. See Arts. **21** and **22.**

(17) The weight of the car $w_t = 12$ tons and the force required will be, by formula **1,**

$$f = 25 \times 12 = 300 \text{ lb.} \quad \text{Ans.}$$

(18) According to formula **3,** the force will be

$$f' = (70 + 20\,x)\,w_t = [70 + (20 \times 6)] \times 12 = 2{,}280 \text{ lb.} \quad \text{Ans.}$$

(19) According to formula **5,**

$$G_s = \frac{\dfrac{2{,}000\,a}{y} - 70}{20};$$

we have, by substituting,

$$G_s = \frac{(\frac{3}{4} \times 2{,}000 \times \frac{1}{8}) - 70}{20} = 5.87 \text{ per cent.} \quad \text{Ans.}$$

(20) (*a*) The most common method of suspending trolley wires in the United States is to suspend them from span wires stretched between poles placed on opposite sides of the road.

(*b*) This method does not obstruct the center of the roadway as the center-pole construction does, and, moreover, there is comparatively little additional overhead work to be done if it is desired later to convert a single-track, overhead system into a double-track road. See Arts. **52** and **53.**

(21) The center-pole construction can be used to good advantage on very wide streets, and especially if it is desirable to give the work a neat and pleasing effect, which may be improved if ornamental center poles are used with arc lamps on the top of every second or third pole. See Art. **54.**

ELECTRIC RAILWAYS.

(PART 3.)

---

(1) According to formula **3**, the resistance per yard of an 80-pound rail $= \frac{.00178}{80} = .00002225$ ohm. The resistance of 2 miles of single rail $= \frac{.00002225}{3} \times 5{,}280 \times 2 = .0783$ ohm. Each bond wire being 1 foot long has a resistance of .00005 ohm. The joints at each end of the bond have a resistance of .0002 ohm, giving .0004 ohm for the two joints of each bond. This added to .00005, the resistance of 1 foot of No. 0000 copper wire, gives .00045 ohm as the total resistance of one rail joint. Now, in 2 miles of 60-foot rails there will be $\frac{2 \times 5{,}280}{60} = 176$ joints. Hence, the resistance of all the joints between the bond wires and rails in a single line of the rails 2 miles long $= .00045 \times 176 = .0792$ ohm. Hence, the total resistance of 2 miles of a single line of rails, including joints and rails $= .0783 + .0792 = .1575$ ohm, and for double track (4 lines of rails) we get the total resistance $= \frac{.1575}{4} = .0394$ ohm. Ans. See Arts. **27** and **30.**

(2) The total drop in the track circuit $= 500 \times .0394 = 19.7$ volts. There will be wasted $19.7 \times 500 = 9{,}850$ watts, or 9.85 kilowatts, in the track circuit. This will amount to $9.850 \times 20 \times 365 = 71{,}905$ kilowatt-hours in one year. Ans.

(3) Since one bond complete, as computed in the answer to question 1, has a total resistance of .00045 ohm, two in parallel will have half this resistance, and the resistance of all the bonds in 2 miles of a single line of rails $= \frac{.0792}{2} = .0396$ ohm. Hence, the total resistance of 2 miles of a single line of rails $= .0783 + .0396 = .1179$ ohm, and for a double track we get the total resistance $= \frac{.1179}{4}$ $= .0295$ ohm. The watts lost in the track circuit given in question 1 were found in the answer to question 2 to be 9,850. The volts drop in the track circuit given in this question $= .0295 \times 500 = 14.75$ volts. Then the loss $= 14.75 \times 500 = 7,375$ watts. Hence, there will be a saving of $9,850 - 7,375 = 2,475$ watts, or 2.475 kilowatts. Ans.

(4) (*a*) Anchor wires are used to relieve the trolley and cross-suspension wires of most of the strain and to prevent the entire trolley line giving away, as it would otherwise do, in case the trolley wire should break. See Art. **1.**

(*b*) Turnbuckles are used to give the anchor or cross-suspension wires the proper tension. They are also sometimes useful in centering the trolley wire. See Art. **5.**

(5) (*a*) The three divisions are feeders, trolley wires, and ground return.

(*b*) The feeders require the most copper. See Art. **21.**

(6) They are insulators especially constructed to withstand considerable tension tending to pull or break the insulator apart. They are used in span, anchor, and other wires that are under considerable tension and yet have to be insulated. See Art. **5.**

(7) 19 feet. See Art. **4.**

(8) According to formula **1,** $A = \frac{W}{10}$; the cross-sectional area $= \frac{70}{10} = 7$ sq. in. Ans. See Art. **25.**

(9) See Art. **10** and Fig. 15.

(10) According to formula **3**, $R_y = \frac{.00178}{W}$; hence, the resistance $= \frac{.00178}{70} = .0000254$ ohm. Ans. See Art. **27.**

(11) According to formula **2**, $R_y = \frac{.000178}{A}$; hence, the resistance of 1 yard of a steel rail $= \frac{.000178}{6} = .0000297$ ohm. Ans. See Art. **26.**

(12) They should be simple, durable, and strong, and if the device has an insulator, this must in addition be effective in preventing leakage. See Art. **13.**

(13) According to formula **4**, $R_m = \frac{.6}{W}$, approximately; hence, the resistance of 1,000 feet of steel rail $= \frac{.6}{60} = .01$ ohm. Ans. See Art. **27.**

(14) It is difficult because the continual vibration of the rail caused by the passing cars tends to mechanically loosen the joints between the rails and the bond wires, and also because corrosion due to moisture and chemical action tends to impair the metallic contact between the rail and bond. For both these reasons, the resistance of the joints tends to continually increase. It is necessary to keep the rails electrically well bonded in order to decrease the drop in the voltage in the return circuit and thus save an unnecessary loss of power, and also to avoid electrolysis in neighboring gas and water pipes and grounded cable sheaths. See Art. **29.**

(15) (*a*) An ordinary wire splice is made by means of the Western Union joint and then soldered, using a non-corrosive flux, such as rosin dissolved in alcohol. For large cables, copper sleeves are used.

(*b*) Trolley wires must be spliced so that the joint is smooth in order that it will present no obstruction to the trolley wheel. For this reason, trolley wires are usually joined by tapered brass sleeves or splicing ears, which

are then filled with solder and cleaned off smooth. See Arts. **14** and **15.**

(16) Since there are four rails in parallel, the resistance per 1,000 feet will be $R_m = \frac{.15}{n}$ (see Art. **27**), and the resistance of 3 miles will be $R = \frac{.15}{80} \times \frac{5,280 \times 3}{1,000} = .0297$ ohm. Ans.

(17) It is more suitable for overhead, underground, and for cross-country lines that do not use the public roads. See Arts. **60** and **64.**

(18) Because the pounding and jolting due to a poor track loosens the truck and motor bolts, wrecks in course of time the suspension rigging, and lets the motor down too low; it causes excessive teetering, setting of springs, breaking of axles; it is hard on the bearings and brushes, with the result that the commutator soon gets out of order. See Art. **38.**

(19) It is a good plan to have two bonds at each rail joint, because if one breaks, the other still preserves the continuity of the rail circuit. See Art. **34.**

(20) (*a*) Girder and T rails are in general use. See Art. **43.**

(*b*) The girder rail is used in cities and towns where it is necessary to have a comparatively flat rail flush with the street paving on account of the wagon traffic. The T rail is used for cross-country, suburban, elevated, and underground roads, where the wagon traffic does not have to be considered. See Art. **44.**

(21) The electrically welded joint usually has the lower resistance when sound, but it is not as strong mechanically as the cast-welded joint. The cast-welded joint is more widely used for this reason. See Art. **37.**

(22) (*a*) The tram rail, which has a flat tram or surface slightly lower than the head of the rail, and the groove

rail, which has a groove in place of the flat surface of the tram rail.

(*b*) The grooved rail, since it does not afford such an easy path for wagon wheels as the tram rail, tends to divert the wagon traffic from the rails, and hence they wear better and last longer. On the other hand, it is difficult to keep ice, dirt, and stones out of the groove, and the presence of this foreign matter increases the power required to propel a car and introduces an element of danger due to the tendency to throw the car off the track; the track must be gauged with exactness, because it offers two chances for the wheels to bind, and for a given shape of rail the shape of wheel must be chosen with more care than for a tram rail. See Arts. **43** and **44.**

(23) (*a*) Ordinary steel **T** rails are generally used. See Arts. **60** and **61.**

(*b*) The third rail may be placed in the center of the track or on one side of the track. See Art. **60.**

ELECTRIC RAILWAYS.

(PART 4.)

---

(1) The total resistance of the track circuit is $\frac{.0111}{1,000} \times 5,280 \times 3 = .1758$ ohm. The drop in the track circuit is $.1758 \times 24 \times 10 = 42.19$ volts. This leaves $110 - 42.19 = 67.81$ volts for the drop e in the feeder and trolley

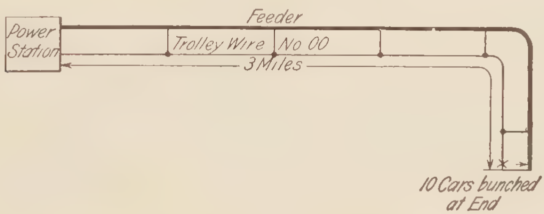


FIG. 1.

wire. By substituting the proper quantities, $L = 5,280 \times 3 = 15,840$ feet and $C = 24 \times 10 = 240$ amperes, in formula **1**, which is circular mils $= \frac{10.8 \times L \times C}{e}$, we get the total number of circular mils required, or $\frac{10.8 \times 15,840 \times 240}{67.81} = 605,475$. No. 00 trolley wire contains approximately 133,000 circular mils. Hence, the number of circular mils required in the feeder, since the trolley wire and feeder are in parallel, is $605,475 - 133,000 = 472,475$. A standard 500,000 circular mil cable would probably be used in such a case. See Art. **5**.

(2) The drop with a uniformly distributed load is one-half that with the same load concentrated at the distant end. See Art. **10.**

(3) It is necessary to see that the wire is sufficiently large to carry the given current without overheating it. This can be readily done by means of the table, Art. **21,** which gives the approximate amount of current that a wire will carry without increasing its temperature much over 25° F. above that of the surrounding air. See Art. **21.**

(4) Since the power station is at the middle of the road, the resistance of the track circuit from the power house to either end of the road is $\frac{.0056}{1,000} \times 5,280 \times 2 = .059$ ohm. The drop in the track circuit to one end is $.059 \times 25 \times 12 = 17.7$ volts. This leaves $100 - 17.7 = 82.3$ volts for the

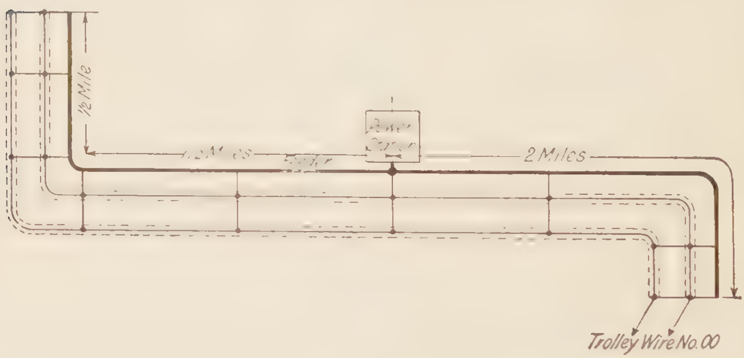


Fig. II.

drop in the feeder and the two trolley wires. By substituting in formula **1**, which is circular mils $= \frac{10.8 \times L \times C}{e}$, we get $\frac{10.8 \times 2 \times 5,280 \times 300}{82.3} = 415,728$ circular mils as the total number required. The two No. 00 trolley wires contain $2 \times 133,000 = 266,000$ circular mils. Hence, the number of circular mils required in the feeder, since the trolley wire and feeder are in parallel, is $415,728 - 266,000$

= 149,728 circular mils. This would require a No. 000 wire. See Art. **8.**

(5) Too low a voltage will cause low speed and trouble with the motors and car equipment, such as roasting of field coils and controller blow-out coils and the slinging of solder out of commutator connections. See Art. **22.**

(6) (*a*) The tread of a car wheel is chilled so that it is very hard for a depth of $\frac{3}{8}$ to $\frac{1}{2}$ inch, and if ground down below this hard surface, the softer iron underneath will stand but little wear.

(*b*) By knocking the flat spot with a hammer, a dent will be made if the hard surface is already worn through at the flat spot, in which case it would be useless to grind down the rest of the wheel surface. If no dent is made, the surface may be trued without going below the chilled iron on the surface. See Art. **49.**

(7) By electrolysis is meant the corrosion or eating away of the rails, lead armor of cables, underground pipes, or other buried metallic conductors by stray current from the street-railway system. See Art. **23.**

(8) The injury occurs at points where the current flows from the lead sheath of cables, pipes, etc. into the earth. See Art. **24.**

(9) There are two advantages: there is less electrolysis of neighboring underground pipes or conductors and there is a saving of from 20 to 40 per cent. in copper due to the higher voltage (1,000) at which the power is transmitted. On the other hand, the high voltage (1,000) is a serious disadvantage on account of the danger to life and property and the difficulty of properly insulating the system. See Art. **30.**

(10) Evidently the maximum drop in the section fed by the No. *1* feeder will occur at the car at the end *e* of the section; the maximum drop in the section fed by the No. *2* feeder will occur at the car at the end *i*; the maximum drop in the section fed by the No. *3* feeder at the car at the

end *a*. Hence, the drop at these points only need be considered. The drop from *d* to *e* calculated by means of formula **3** $= \frac{14.4 \times 2,640 \times 25}{133,000} = 7.14$ volts. The cross-section of the overhead wires from *c* to *d* = 133,000 + 133,000 = 266,000 circular mils. The current in this portion of

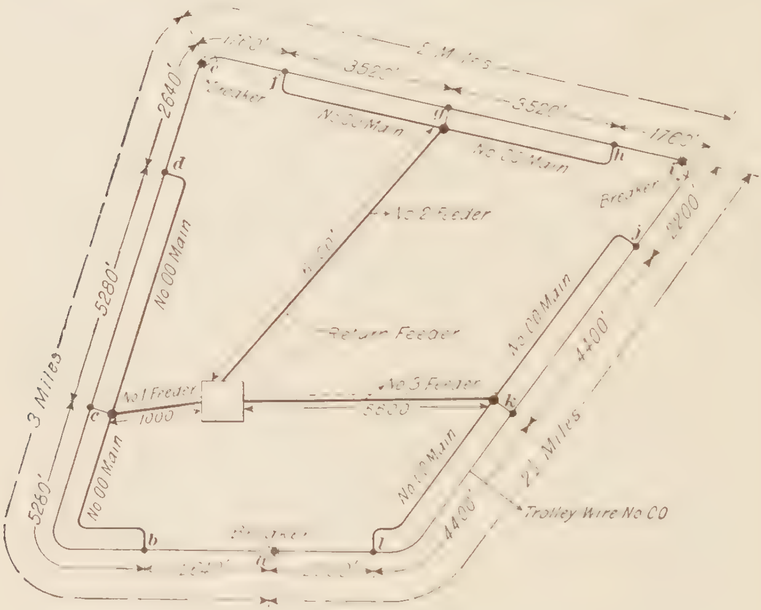


FIG. III.

the circuit is $2 \times 25 = 50$ amperes and the distance 5,280 feet; hence, the drop from *c* to $d = \frac{14.4 \times 5,280 \times 50}{266,000}$ = 14.29 volts. This leaves 50 − (7.14 + 14.29) = 28.57 volts for the drop in the No. *1* feeders (outgoing and return feeders combined). The current in these feeders is $4 \times 25 = 100$ amperes, and by formula **1** they should have a sectional area of $\frac{10.8 \times 2 \times 1,000 \times 100}{28.57} = 75,604$ circular mils. Hence, the feeders for section *1* would consist of No. 1

B. & S. wire. The drop from h to $i = \frac{14.4 \times 1{,}760 \times 25}{133{,}000}$ $= 4.76$ volts. The cross-section of the overhead wires from g to $h = 266{,}000$ circular mils, the current is 50 amperes, and the distance 3,520 feet; hence, the drop from g to h by formula **3** is $\frac{14.4 \times 3{,}520 \times 50}{266{,}000} = 9.53$ volts. This leaves $50 - (9.53 + 4.76) = 35.71$ volts for the drop in the No. *2* feeders, which carry $4 \times 25 = 100$ amperes. By formula **1**, these feeders should have a cross-sectional area of $\frac{10.8 \times 2 \times 6{,}000 \times 100}{35.71} = 362{,}923$ circular mils, corresponding to about three No. 00 wires in parallel. Hence, there would be required six No. 00 wires between the power station and the point g, or, what is more probable, two cables of about 350,000 circular mils each would be used. The drop from l to $a = \frac{14.4 \times 2{,}200 \times 25}{133{,}000} = 5.95$ volts. The cross-section of the overhead wires from k to $l = 266{,}000$ circular mils. The current in this portion $= 50$ amperes and the distance 4,400 feet; hence, the drop from k to l by formula $\mathbf{3} = \frac{14.4 \times 4{,}400 \times 50}{266{,}000} = 11.91$ volts. This leaves $50 - (11.91 + 5.95) = 32.14$ volts for the drop in the No. *3* feeders, which carry $4 \times 25 = 100$ amperes. By formula **1**, these feeders should have a cross-sectional area of $\frac{10.8 \times 2 \times 5{,}600 \times 100}{32.14} = 376{,}400$ circular mils. This will require 11,200 feet of cable 376,400 circular mils in cross-section, or three No. 00 wires, in both the outgoing and grounded-return circuits. As 376,400 is not a standard size of cable, either the 350,000 or 400,000 circular mil sizes would probably be used, the latter being preferred.

(11) (a) The drop in the track circuit from l to a $= .0111 \times \frac{2{,}200}{1{,}000} \times 25 = .61$ volt. The drop in the track circuit from k to $l = .0111 \times \frac{4{,}400}{1{,}000} \times 50 = 2.44$ volts. The

drop in the trolley wire from l to $a = .08 \times \frac{2,200}{1,000} \times 25 = 4.40$ volts. The resistance of the two parallel No. 00 wires from k to $l = \frac{.08}{2} = .04$ ohm per 1,000 feet; hence, the drop from k to l through these two wires $= .04 \times \frac{4,400}{1,000} \times 50 = 8.80$ volts. The drop (both ways) in the No. 3 feeders, assuming each one to contain 376,400 circular mils, may be obtained by solving formula **1** for e. Doing this, we get $e = \frac{10.8 \times 2 \times 5,600 \times 100}{376,400} = 32.14$ volts. Hence, the total drop to the car at $a = 32.14 + 8.80 + 4.40 + 2.44 + .61 = 48.39$ volts. Ans.

(b) In the former question, 50 volts drop was allowed at the car at a; hence, there is only a difference of 1.61 volts in the drop as calculated by the two methods.

(12) With the positive pole connected to the trolley, whatever electrolysis occurs is apt to take place and be the most severe over a limited area near the power station where the currents leave the underground pipes. This limited area can be thoroughly protected from serious damage by providing an adequate return path for the current; whereas if the current flows in the opposite direction, the electrolysis would occur at outlying points, where it would be difficult and expensive to prevent injury. See Art. **25.**

(13) The double overhead-trolley and conduit systems, in which the rails are not used as part of the return circuit, and also roads that are operated by alternating current do not produce electrolysis. Electrolysis can be considerably reduced by operating the cars on a three-wire system. See Arts. **29** and **30.**

(14) One large and one small lathe for ordinary work, a speed lathe, a metal saw, one large and one small drill press, a planer and shaper, a bolt-cutting machine (with right- and left-hand dies), a milling machine, a wheel press, an axle

straightener, emery wheels, grindstone, a power hack saw, a ratchet drill, a punch press, and a power hammer. See Art. **42.**

(15) Flats, as they are called, are spots on the bearing or tread of car wheels that are worn down below the true or correct cylindrical surface of the rest of the wheel. They are removed by means of a machine that holds and revolves an emery wheel against the tread of a revolving car wheel, thus grinding the tread to a true cylindrical surface. See Art. **49.**

(16) It depends on the strength of the current that flows from the metal at a given point into the earth. If 4 amperes flow from 1 square inch of the metal pipe or other conductor in the earth, it will do twice the damage that would be done by 2 amperes flowing from the same square inch into the earth. See Art. **24.**

(17) It should first be determined by a proper test, such as given in Art. **34,** whether the feeder or track circuit is at fault and which it will pay the best to improve.

(18) The air may be used to blow the dust and dirt out of motors, controllers, etc., and sometimes for lifting cars and heavy work around the lathe and other machines. See Art. **41.**

(19) The trouble is first localized near the station by connecting the positive pole of the dynamo to the line, next the ground-return circuit is made as good as possible by thorough track bonding, and finally the danger point or points should be located by means of tests with a voltmeter, and at the danger points the cable sheaths, water pipes, etc. should be bonded to the neighboring rails and in some cases to return feeders, by means of which the current may flow from the danger points to the power station, instead of flowing into the moist earth and causing electrolysis. See Art. **28.**

(20) The car barn, if possible, should be fireproof, and at any rate there should be ample provision for quickly running

the cars on the ground floor out of the barn in case of fire. For this reason, the car bodies on the street floor should not be set on horses or barrels, but on temporary trucks at least, and one transfer table should not be depended on for transferring all cars to the street track. See Art. **36.**

(21) (*a*) About 200 feet of pit room. See Art. **37.**

(*b*) A pit should be 4 feet 8 inches deep and never shorter than the longest car to be placed over it. See Art. **37.**

ELECTRIC RAILWAYS.

(PART 5.)

---

(1) The starting rheostat is generally hung wherever there is room under the car; the lightning arrester and fuse box are generally placed on one side under the car sill. See Art. **8.**

(2) (*a*) The rheostatic method of control is that in which a rheostat connected in series with a car motor is the only means used to control the speed of the car.

(*b*) The most important objection is the fact that this method is very wasteful of power, especially at low speeds. See Art. **10.**

(3) An ordinary double truck has four wheels, all the same size. It can take a motor on each axle and there are two trucks to a car. A maximum-traction truck has two large wheels and two small ones, the idea being to throw most of the weight (about 70 per cent.) on the large wheels, to whose axle the motor is hung and geared. See Art. **5.**

(4) (*a*) Long double-truck cars are especially suitable for long hauls where the stops are not too frequent, because double trucks are easier than single trucks on the car body, line work, track, and passengers.

(*b*) Double-truck closed cars are not as suitable for local runs having a heavy traffic, because they require more power to start and a longer time to load and unload. See Art. **3.**

(5) (*a*) The starting rheostats are used to prevent too great a rush of current when starting. They are also used when changing the motor connections from series to parallel, or *vice versa*, so as to make the change more gradual.

(*b*) The rheostat, if not burned out, will become unduly heated by remaining in the circuit too long. See Art. **8.**

(6) For going up grades on icy roads, the single truck is superior to the other two mentioned. See Art. **4.**

(7) It is quite extensively used in connection with mine-haulage plants and hoisting apparatus and where gradual variations in speed are desired. See Art. **10.**

(8) (*a*) The K10 is a lighter controller, being designed for 35-horsepower motors, while the K11 is designed for 50-horsepower motors.

(*b*) It is designed for exactly the same class of work for which the K2 controller has been so extensively used. The K10 has four resistance notches, instead of three, as in the K2 controller; and, furthermore, the K10 has no field shunts. Consequently the connections are simpler than those for the K2 controller and a smoother acceleration is obtained. See Art. **46.**

(9) It is the method of control in which the field is not shunted, the regulation being effected either by the insertion of resistance in series with the motor or by the series-parallel combinations. See Art. **13.**

(10) If the armature makes 4.8 revolutions while the car axle makes 1, then the car axle must have a gear with 4.8 times as many teeth as the armature gear; hence, the number of teeth on the car-axle gear must equal $4.8 \times 15 = 72$ teeth. See Art. **67.**

(11) (*a*) It is a method in which speed variations are obtained by coupling the two motors required either in series or in parallel. When starting and when changing from series to parallel positions, a resistance that is gradually cut out is included in the circuit in order to give a

smooth acceleration to the car, but this resistance is entirely cut out by moving the handle to the running positions, as soon as the car gets under headway, and hence it is not used when the controller handle is on the running notches or positions. A higher speed is obtained by shunting the field coils with a resistance in the last series and multiple notches.

(*b*) It is an economical method, because there is no loss of power in the running positions of the controller, and a low speed can be obtained without the use of resistance. See Art. **23.**

(12) A rheostat is placed in shunt with the field coils so as to control the proportion of the total current that will flow through the field coils, and hence the strength of field and the speed. See Art. **13.**

(13) The car will continue to start and run with the faulty motor, but the brushes will spark badly, and in course of time the field coils will bake and become weak, lowering the counter E. M. F. of the armature and allowing so much current to flow through it that the fuses begin to blow. The armature would run, but there would be a great consumption of current. See Art. **89.**

(14) By the proper manipulation of one or the other of these two switches the car may be run on one motor, if the other motor or any part of its circuit gets out of order. See Art. **38.**

(15) The blow-out coil, or "blow" coil, as it is often called, is used to produce a magnetic field that blows out the arc that would otherwise hold on and cause blistering and burning of the contacts in the controller. See Art. **16.**

(16) The usual method is to connect the motors in pairs in parallel and then to treat the two pairs as if they were single motors, operating them by the series-parallel method, as with a regular two-motor equipment. See Art. **60.**

(17) The K11 controllers, being designed for larger motors (50 horsepower) than the K2, have contacts of larger current capacity. The K11 has four resistance notches

instead of three, and, furthermore, no provision is made in the K11 controller for shunting the field coils of the motors, as in the K2 controller. The K11 controller has consequently only two running notches, one in the series and one in the parallel position, while the K2 has four running notches, two in the series and two in the parallel positions. See Arts. **44** and **45.**

(18) The interlocking device makes it impossible to move the reversing lever on the controller unless the power drum is at the off-position. See Art. **19.**

(19) Because the motors would have to run so slow, if no reduction gearing is used, that they would be heavy and bulky for their output. See Art. **66.**

(20) They should be so connected in series that adjacent pole pieces will have opposite polarities. See Art. **91.**

(21) The path is as follows: W–K–K–FB–choke coil–

$$O\text{–}T\text{–}M\text{–}X\text{–}Y\text{–}T\text{–}a\text{–}R_4\text{–}R_4\text{–}r_4\text{–}r_5\text{–}R_5\text{–}t\text{–}\left\{\begin{array}{l} R_6\text{–}19\text{–}b\text{–}15\text{–}15\text{–}15\text{–} \\ 19\text{–}19\text{–}19\text{–}1\text{–}A_1\text{–}A_1\text{–} \end{array}\right.$$

$$\left.\begin{array}{l} 15\text{–}3\text{–}A_2\text{–}A_2\text{–}AA_2\text{–}A_2\text{–}AA_2\text{–}AA_2\text{–}F_2\text{–}F_2\text{–}F_2\text{–}F_2\text{–}E_2 \\ AA_1\text{–}A_1\text{–}AA_1\text{–}AA_1\text{–}2\text{–}F_1\text{–}F_1\text{–}F_1\text{–}E_1\text{–}E_1\text{–}E_1\text{–}E_1\text{–}d \end{array}\right\}\text{–Ground.}$$

(22) See Fig. 24.

(23) The path is as follows: W–K–K–FB–T–a–a_5–4–

$$5\text{–}\left\{\begin{array}{l} 13\text{–}14\text{–}9\text{–}F_1+\text{–}F_1+\text{–}F_1+\text{–}F_1-\text{–}F_1-\text{–}F_1-\text{–}A_1+\text{–}A_1+\text{–} \\ b\ \ b_1\text{–}6\text{–}8\text{–}c_1\text{–}c\text{–}7\text{–}17\text{–}18\text{–}12\text{–}11\text{–}F_2+\text{–}F_2+\text{–}F_2+\text{–}F_2-\text{–} \end{array}\right.$$

$$\left.\begin{array}{l} A_1+\text{–}A_1-\text{–}A_1-\text{–}15\text{–}16\text{–}R_4\text{–}R_4\text{–}d\text{–}d_2 \\ F_2-\text{–}F_2-\text{–}A_2-\text{–}A_2-\text{–}A_2-\text{–}A_2+ \end{array}\right\}\text{–Ground.}$$

(24) The path is as follows: W–circuit-breaker–kicking

$$\text{coil–blow-out coil–}T\text{–}1\text{–}R_5\text{–}19\text{–}\left\{\begin{array}{l} 19\ \left\{\begin{array}{l} 19\text{–}A_1\text{–}A_1\text{–}A_1\text{–}AA_1\text{–} \\ 19'\text{–}A_3\text{–}A_3\text{–}AA_3\text{–}AA_3\text{–} \end{array}\right. \\ 2\text{–}15\text{–}15\text{–}\left\{\begin{array}{l} 15\text{–}A_2\text{–}A_2\text{–}A_2\text{–} \\ 15'\text{–}A_4\text{–}A_4\text{–} \end{array}\right. \end{array}\right.$$

$$\left.\begin{array}{l} \left.\begin{array}{l} AA_1\text{–}AA_1\text{–}F_1\text{–}F_1\text{–}F_1\text{–}E_1\text{–}E_1E_3\text{–}E_1E_3\text{–}4 \\ F_3\text{–}F_3\text{–}E_3\text{–}E_1E_3\text{–}E_1E_3\text{–}4 \end{array}\right\} \\ \left.\begin{array}{l} AA_2\text{–}AA_2\text{–}AA_2\text{–}F_2\text{–}F_2\text{–}F_2\text{–}E_2 \text{———} \\ AA_4\text{–}AA_4\text{–}F_4\text{–}F_4\text{–}E_4 \text{————} \end{array}\right\} \end{array}\right\}\text{–Ground.}$$

All four motors are in parallel on this notch and there is no resistance in ahead of them.

(25) The path of the current is as follows: W–K–K–$F\,B$–choke coil–O–T–M–X–Y–T–a–R_1–R_1–r_1–r_4–R_4–t–19–S–E_1–E_1–E_1–c–15–15–15–15–3–A_2–A_2–A_2–AA_2–AA_2–AA_2–4–F_2 F_2–F_2–F_2–E_2–G. The No. 1 motor is cut out and the current passes through the No. 2 motor and all the resistance.

(26) The current through the fields is reversed, whereas with the General Electric controllers it is the current through the armatures that is reversed. See Art. **50.**

(27) See Art. **82.**

(28) See Art. **86.**

ELECTRIC RAILWAYS.

(PART 6.)

(1) (*a*) If the pressure is too light, the trolley wheel will be continually jumping off the wire at every kink or turn; if the pressure is too great, it causes unnecessary wear of the trolley wire, wheel, and axle and also makes it much more difficult to get the wheel back on the wire after it has jumped off.

(*b*) A pressure of about 15 pounds. See Art. **9.**

(2) The lamp circuit is tapped in ahead of the hood switch, so that the opening of the hood switch, which is very desirable in case it is necessary to look for trouble in the controller and motor circuits, will not put out the lights and so leave the car in total darkness. See Art. **45.**

(3) The object of the canopy switch is to furnish a simple and ready means for entirely disconnecting the motor circuits from the trolley pole independently of the controllers, in case there should be something wrong with the latter. See Art. **10.**

(4) Make a diagram similar to Fig. 56.

(5) All lightning arresters should be carefully inspected after each thunder storm to see that the air gaps have the proper width and that the ground wire especially is not loose at the binding posts or broken. See Art. **24.**

(6) First, a double truck consists of two single trucks, and hence each truck must have a complete set of brakes;

second, since both trucks revolve around independent centers, provision must be made to preserve the action and efficiency of the brakes whatever may be the angle that either truck makes with the center line of the car body; third, if all the wheels of the truck are not the same size, as is the case on maximum-traction trucks, the different size wheels will be sustaining a different percentage of the total weight of the car, and hence the different size wheels should have a brake pressure proportional to the weight that they sustain. This requires a special arrangement of the brake rigging. See Art. **63.**

(7) The harp should be narrow and smooth; all edges should be nicely rounded off to avoid catching in the line work when the trolley wheel flies off the wire. See Art. **4.**

(8) The General Electric canopy switch is provided with a magnetic blow-out device, consisting of an iron core over which is wound a coil of wire that is connected in series with the switch contacts. When the circuit is broken, the magnetic circuit is also broken at the same place and the magnetic field blows out the arc. See Arts. **12** and **13.**

(9) (*a*) It is used to start the compressor when the pressure in the reservoir or supply cylinder falls below a certain point and for stopping it when the pressure reaches the value at which it is intended to operate the brake cylinder.

(*b*) See Art. **74.**

(10) The multiple-unit system is intended for operation of trains such as heretofore have been hauled by steam locomotives, that is, for trains on overhead, underground, and long-distance surface roads. This system is not intended for ordinary street-railway service, where trains of three or more cars are not used. See Art. **100.**

(11) Because electric heaters occupy no passenger space, they distribute the heat more uniformly, they are cleaner than stoves, and they allow the heat to be more readily regulated. See Art. **31.**

(12) See Art. **11.**

(13) No. 14 B. & S. for 30-horsepower equipments and No. 12 B. & S. for 50-horsepower equipments. See Arts. **16** and **17.**

(14) (*a*) A single unit consists of a single car with a full equipment for heat, light, brakes, and motive power.

(*b*) Several single units, as just explained, coupled together into one train and arranged so that the motors on all cars can be started and controlled simultaneously from the platform of any car. See Arts. **100** and **101.**

(15) There are two coils of different resistance in each heater, the same coils in all heaters in one car being joined in series, thus making two separate circuits of different resistance. By means of the switch used, current may be sent through either the higher or lower resistance circuit or through the two in multiple, thus giving three different degrees of heat. See Arts. **33, 35, 36, 37, 38, 39.**

(16) (*a*) and (*b*). See Arts. **20** and **21.**

(17) If one of the connecting wires becomes grounded through the frame of the car, one or more coils less than the regular number in one or both heater circuits may be connected directly between the trolley and ground, and hence some heater coils may be burned out because of the excessive current. Again, the top- and bottom-heater circuits may be interchanged at one or more points, thereby placing some high-resistance coils in series with some low-resistance coils. This is very likely to burn out the high-resistance coils that happen to be connected in series with some of the low-resistance coils, especially if there are only one or two high-resistance coils in the low-resistance coil circuit. In any case, the high-resistance coils are apt to become overheated. See Art. **40.**

(18) (*a*) The so-called straight air and automatic air brakes.

(*b*) The straight air brake being simpler and more reliable is most suitable for ordinary roads, where only single cars or a car and only one trailer are operated. However,

this straight air brake is not suitable for elevated and underground roads, where heavy trains of considerable weight and length are operated and which require the setting of brakes on each car at the same time. For this purpose, the automatic air brake, which allows the simultaneous setting and releasing of all brakes, is more suitable. See Arts. **67** and **68.**

(19) The supply cylinder is connected to the brake cylinder, into which the compressed air is admitted whenever the brakes are put on. The piston rod of the brake cylinder operates the brake mechanism about in the same manner as the ordinary hand-brake. The motorman has a switch or lever that gives him control of the valves that allow compressed air to pass from the supply cylinder into the brake cylinder or out of the brake cylinder into the atmosphere. A third position of the switch blanks all the air passages so that there can be no movement of air in any direction. In the straight air equipment, the air passes directly from the reservoir to the brake cylinder, whereas in the automatic air equipment it passes from an auxiliary reservoir to the brake cylinder by way of a triple valve. See Arts. **67, 69,** and **70.**

(20) By properly changing the connections by means of the controller handle, the car motors may be made to operate as dynamos as long as the car is in motion and to supply current to an electromagnetic brake. They may be operated whether the trolley wheel is on or off the trolley wire. In order to generate any current, and so cause the electromagnetic brakes to take hold, the car must be in motion, and hence hand-brakes must be used to hold a car on a grade after the electric brake has brought the car nearly to a standstill. See Art. **86.**

(21) (*a*) To avoid sliding, the pressure applied to a brake shoe should be a little less than the weight supported by the wheel.

(*b*) The greater the speed, the less will be the amount of friction produced by a given pressure, so that at high speeds

a much greater pressure can be applied without causing the wheel to slide than at low speeds; hence, to bring a car originally running at high speed to a stop, the brake should be released a little as the car slows down to avoid slipping at the lower speed. See Arts. **54** and **55.**

(22) The General Electric brake produces friction between two rubbing iron plates. This friction is caused by the magnetic attraction of the core of an electromagnet for its armature, which is an iron plate fixed to the wheel axle. In the Westinghouse brake the regular brake shoes are used, and in addition there is a pair of shoes that press on the track. When the track brake is set by an electromagnet, it also sets the regular wheel brakes by means of a set of levers. In both the General Electric and Westinghouse systems, the current for the electromagnetic device is supplied by the motors acting as generators. In the Westinghouse electric-brake system, the connections are arranged so that either the regular car starting resistance or the electric car heaters may be used as the controlling resistance for the brakes, thereby allowing the use of heat that would otherwise be wasted. See Arts. **87**, **88**, and **99.**

(23) Where the ground wire is fastened to the truck or motor and in the main switch, if there is one, that controls all the lamp circuits. The grounded wire is, however, the source of most of the trouble. See Art. **41.**

(24) (*a*) There are five positions.

(*b*) They are called: lap, service stop, emergency stop, slow release and running, and quick release. See Art. **72.**

(25) Because it is impractical to make efficient lamps that can be connected directly across the 500-volt circuit, whereas 100- to 110-volt lamps are about the most efficient, the easiest obtained, and the cheapest made, and hence are the ones used. See Art. **45.**

(26) See Art. **25.**

INTERIOR WIRING.

(PART 1.)

(1) If the drop is excessive, the lamps will not burn with uniform brilliancy, because the lamps near the source of supply get a higher voltage than those far removed, and those lamps on which the voltage is low would give an unsatisfactory light. See Art. **77.**

(2) (*a*) Slow-burning weather-proof wire is allowable for open work in dry places, such as mill wiring, etc.

(*b*) It must be supported clear of all woodwork by means of porcelain, glass, or other non-combustible, non-absorptive insulators. See Art. **59.**

(3) A fuse block or circuit-breaker must be placed as near as possible to the point where the service wires enter the building. Fuse blocks must be placed wherever there is a change in the size of the wire, unless the fuse in the cut-out protecting the larger wire will protect the smaller wire also. See Art. **51.**

(4) (*a*) If lamps are burned after they become dim, they give out very little light compared with the power that they consume; i. e., the watts per candlepower become very high, and it therefore pays better to put in new lamps. See Art. **14.**

(*b*) The effect of burning a lamp above its rated voltage is to increase the candlepower, but at the expense of greatly shortening the life of the lamp. See Art. **14.**

(5) Calculate the wiring as if it were for 220 volts. This will give the size of the outside wires. Make the middle wire of such size that it can safely carry the current required by one side of the system. See Art. **86.**

(6) If there are 120 lamps, there will be 40 lamps on each branch, or $\frac{40}{2} = 20$ amperes. Hence, from formula **1,**

$$C_m = 20 \times 1.73 = 34.6 \text{ amperes. Ans.}$$

Here C_m is the current in each of the main wires. See Art. **44.**

(7) (*a*) From 3.1 to 5 watts per candle. See Art. **15.**

(*b*) Total watts $= 32 \times 4 = 128$. Voltage $= 110$.

Hence, $\text{Current} = \frac{128}{110} = 1.16$. Ans.

(8) (*a*) Cut-outs are used to prevent wires being overloaded. They open the circuit whenever the current exceeds the allowable amount and thus prevent the wires from being overheated and burned out.

(*b*) They usually take the form of a piece of soft, fusible wire, which melts and opens the circuit whenever the current becomes excessive. These fuses are provided with metal terminals that are attached to corresponding terminals mounted on a slate or porcelain base. In many cases the fuse is enclosed in order to protect it from air-currents and to keep it from coming in contact with other substances. See Art. **50.**

(9) There will be 250 lamps on each side of the two-phase system; hence, the current in each line will be $250 \times \frac{1}{2} = 125$ amperes. See Art. **45.**

(10) See rule *c*, Art. **26.**

(11) The open arc burns exposed to the atmosphere, whereas the enclosed arc is confined in a small globe from which the oxygen is practically all burned out. The result is that the carbon burns very slowly, and such lamps will burn 100 to 150 hours without being retrimmed. The

enclosed arc is longer than the open arc and requires a higher voltage. See Arts. **20** to **23,** inclusive.

(12) (*a*) The total current is 250 amperes, allowing $\frac{1}{2}$ ampere per lamp. Resistance $= \frac{E}{C} = \frac{5}{250} = .02$ ohm. Total length of line wire is $400 \times 2 = 800$ feet, or .8 thousand feet. The resistance per 1,000 feet must, therefore, be $\frac{.02}{.8} = .025$ ohm. A No. 0000 wire has a resistance of .049 ohm per 1,000 feet, as may be seen by consulting Table V, so that two No. 0000 wires in multiple will have a resistance of .0245 ohm per 1,000 feet and will answer in this case. See Art. **81.**

(*b*) If carrying capacity alone were considered, No. 000 weather-proof wire would answer, because the Underwriters allow 262 amperes for this size of wire.

(13) The carrying capacity of rubber-covered wire is lower than that of weather-proof wire, because the rubber covering is subject to gradual deterioration under the action of heat. See Art. **30.**

(14) Because a resistance must be used in series with these lamps, and a portion of this resistance may just as well be in the branch wires connecting the lamp with the mains. Of course, no wire smaller than No. 14 should be used. See Art. **24.**

(15) (*a*) See Art. **80.**

(*b*) A mil is equal to $\frac{1}{1000}$ inch.

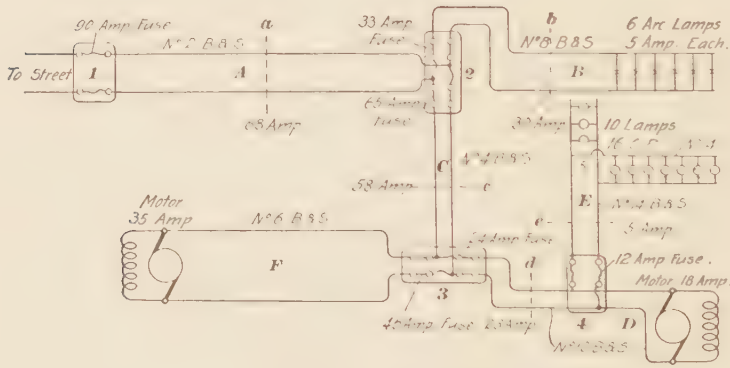
(16) The amount of energy supplied to any one circuit dependent on one cut-out is limited to 660 watts by rule *d*, Art. **51**; hence, the number of lamps allowable is easily determined. About 10 16-candlepower lamps per circuit is usually taken as the limit.

(17) See Art. **3.**

(18) The illustration shows the wiring provided with the necessary cut-outs and with the currents indicated in the various parts.

(*a*) Current at *a*, 88 amperes; *b*, 30 amperes; *c*, 58 amperes; *d*, 23 amperes; *e*, 5 amperes.

(*b*) The sizes of wire will be No. 2 for section *A*, No. 8 for *B*, No. 4 for *C*, No. 10 for *D*, No. 14 for *E*, No. 6 for *F*. See Underwriters' Table, Art. **30.** In each case the wire has been taken that is on the large side, so that the carrying capacity will be ample. If the distances were short, it is probable that so many different sizes would not be used. For example, sections *C* and *F* might both be No. 4, although No. 4 is not absolutely necessary for section *F*. If, however, the distances were long, it would pay to use the different sizes, as indicated.



(*c*) The actual arrangement of cut-outs may vary considerably. A cut-out must be placed at each point where there is a change in the size of the wire, and a main cut-out should, therefore, be placed at *1*, and 90-ampere fuses would be the greatest allowable size to use in it. At *2* we may place a single branch block for *C* and a main block for *B*, or we may use two single branch blocks or one double branch block. In the figure, a double branch block *2* is shown, the side connecting to *B* being fused with fuses not larger than 33 amperes capacity, and the side connecting to *C* with fuses not exceeding 65 amperes capacity. At *3*, a double branch block may also be used, one side being fused

for 24 amperes capacity and the other for 46 amperes capacity, as indicated. To supply branch *E*, a single branch block *4* will be required, and its fuse must not be over 12 amperes capacity. No branch block will be required at *5*, because the size of wire is not changed there. The current capacity of the fuses indicated in the figure is the same as the current capacity of the wires that they protect. In practice, however, fuses of standard size would be used, and these might not always be of the same capacity of the wire. In any event, the rated capacity of the fuse should not exceed the allowable carrying capacity of the wire it protects.

(19) Safety, satisfactory operation, convenience and neatness, economy. See Art. **2.**

(20) The effect is to greatly increase the drop, because the low-voltage lamps require a larger current than the high-voltage ones and the line resistance is the same in both cases. The low voltage, of course, results in unsatisfactory service, to say nothing of the danger of overloading the wiring that is introduced by the change. See Art. **84.**

(21) See rule *c*, Art. **53.**

(22) (*a*) No. 14 B. & S. See rule *a*, Art. **26.**

(*b*) The current-carrying capacity as given by the Underwriters.

(23) The wiring may be divided into distribution circuits and mains. The former run to the lamps from the distributing centers and the latter connect the outside lines to the distributing centers. See Art. **48.**

(24) (*a*) It effects a considerable saving in the amount of wire required to transmit the current, because it admits the use of a higher voltage than the two-wire system.

(*b*) If one side of the system is loaded much heavier than the other, the voltage becomes unbalanced, and the devices connected to the lightly loaded side have a higher voltage thrown on than they are intended for. The wiring is also

more complicated than the two-wire system. See Arts. **38** and **39.**

(25) Because if they are run separately, the inductive effect may cut down the voltage supplied to the lamps. See Art. **33.**

(26) (*a*) Because plaster and cement are likely to corrode the insulation and break it down.

(*b*) Staples do not insulate the wire and are likely to cut into the insulating covering with which the wire is provided. See Art. **34.**

INTERIOR WIRING.

(PART 2.)

---

(1) A line 120 feet long having a drop of 3 volts would be the same size as a line $\frac{120}{3} = 40$ feet long having a drop of 1 volt. In Table I, under 40 and on the same horizontal line with 30, we find No. 6 as the size wire required.

(2) $\frac{1}{8}$ inch $= 125$ mils. $125 \times 125 = 15{,}625$ circular mils. See Art. **6.**

(3) Tests should be made to see if all connections are correct, and also to detect any grounds or crosses between wires. All circuits should be tested before fixtures of any kind are put up, and each fixture should be tested after it is wired, but before it is put in place. See Art. **71.**

(4) (*a*) See Art. **73.**

(*b*) Before the building is lathed and plastered.

(5) A magneto-bell, commonly called a magneto, that is capable of ringing its own bell through a resistance of at least 5,000 ohms is generally used.

(6) The total current $= 80 \times \frac{1}{2} = 40$ amperes. By formula **1** the resistance per 1,000 feet r_m of the proper size wire to use equals $\frac{2 \times 1{,}000}{2 \times 200 \times 40} = .125$ ohm per 1,000 feet. This would require a No. 1 wire, which has a resistance of .124 ohm per 1,000 feet.

(7) Diameter in mils $= \sqrt{10,816} = 104$ mils $= .104$ in. See Art. **6.**

(8) The voltage across the outside wires at the lamps $= 220 - 4 = 216$ volts. Substituting in formula **7,** we have

$$\text{Current} = \frac{60 \times 52}{216} = 14.4 \text{ amperes. Ans.}$$

(9) As in Art. **12,** divide the current by the drop, which gives $\frac{30}{3} = 10$. Now follow down in the column under 10 amperes until the nearest distance to 120 feet is obtained. This will be found to be 121, and to the left of this in the first column will be found the size of wire required, namely, No. 6 B. & S.

(10) The 50 lamps will require 25 amperes. Substituting the values given in formula **5,** we have circular mils $= \frac{21.6 \times 25 \times 150}{2} = 40,500$, or between a No. 4 and No. 5 B. & S. No. 4 wire would be used.

(11) The total resistance of the line should be $\frac{2}{40} = .05$ ohm. Since this line is 200 feet long, counting both ways, then the resistance per 1,000 feet must be $\frac{.05}{200} \times 1,000 = .25$ ohm. The resistance of a No. 6 wire per 1,000 feet $= .394$ ohm. Let $r_1 = .394$ ohm and $r_2 =$ the resistance per 1,000 feet of the wire required. Then, by substituting in the formula $\frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2}$, we have $\frac{1}{.25} = \frac{1}{.394} + \frac{1}{r_2}$, or $\frac{1}{r_2} = \frac{1}{.25} - \frac{1}{.394} = \frac{.394 - .25}{.25 \times .394}$; hence, $r_2 = \frac{.25 \times .394}{.144} = .684$. A No. 8 B. & S. gauge wire, resistance .6271 ohm per 1,000 feet, most nearly meets this requirement. See Art. **17.**

(12) (*a*) See Art. **18.**
(*b*) See Art. **19.**

(13) (*a*) Wooden molding may be used in finished houses on ceilings and walls, and in show windows for temporary purposes, where it is desirable to hide the wire and give the work a neat appearance.

(*b*) It must not be used in concealed work nor in any damp places or where the difference of potential is over 300 volts. See Art. **69.**

(14) The constant motion and vibration of the ship, which tend to chafe and break the wires; also the constant presence of dampness. See Art. **76.**

(15) (*a*) A main switch and cut-out.

(*b*) The cut-out should be placed nearest the point where the wires enter, then the switch, and finally the meter. See Art. **34.**

(16) By means of two three-point switches, one at each point from which it is desired to control the lamps. Make a sketch similar to (*a*) or (*b*), Fig. 18. See Art. **37.**

(17) So that if a wire comes in contact with any section of a conduit or fitting, there will be afforded a direct path to ground through which current may escape to earth. This prevents the current leaking to ground through any other paths and thereby reduces the likelihood of a fire. See Arts. **62** and **63.**

(18) (*a*) Because it is not waterproof and is, therefore, not suitable for use in damp places.

(*b*) Lined and unlined iron pipe.

(19) The loop system is one in which the same pair of wires passes in series through all outlets at which lamps to be connected on that one circuit are located; that is, no branch circuits are tapped on except at outlet or junction boxes. See Art. **57.**

(20) The smaller wire must be protected by a cut-out. See Art. **59.**

(21) The wires must be brought out, for combination fixtures, through insulating tubes or an approved outlet insulator in such a manner that they cannot touch gas pipes, metal work, or plaster. At outlets where there are no gas pipes, ordinary porcelain tubes may be used. See Art. **22** and rule *e*, Art. **23.**

(22) They must be rigidly supported on non-combustible, non-absorptive insulators that keep the wires at least 1 inch from the surface wired over, and should be kept at least 10 inches apart and run on separate timbers or studding whenever possible. In some cases, especially where a large number of wires come together near the junction or panel boards, it is impossible to observe this rule absolutely, and the inspectors will usually pass work in such cases that does not fully meet the requirements, provided wires are kept at least $2\frac{1}{2}$ inches apart or are run in an armored cable or conduit. See Art. **23.**

(23) (*a*) Since the two wires have a greater surface area than the one wire of equivalent cross-section, they can radiate the heat faster and hence can safely carry more current.

(*b*) Since the resistance of the two wires in parallel is equal to that of the one larger wire of equivalent cross-section, then the drop, which is equal to $C \times R$, will be the same in both. See Art. **16.**

(24) The resistance of the line (both ways) $= \frac{3}{50 \times \frac{1}{2}} = .12$ ohm. Total length of line $= 2 \times 100 = 200$ feet. The resistance of 1,000 feet of No. 14 $= 2.521$ ohms; hence, the resistance of 200 feet $= \frac{2.521 \times 200}{1{,}000} = .5042$ ohm. All the wires in multiple are to be No. 14, then each wire will have a resistance of .5042 ohm, and the combined resistance must equal .12 ohm. Hence, if $x =$ the number of No. 14 wires in multiple and R the combined resistance $= .12$ ohm, then we have $\frac{.5042}{x} = .12$, or, from the formula given in Art. **17,** $\frac{1}{.12} = \frac{x}{.5042}$, from either of which $x = 4.20$. Hence, four No. 14 wires in parallel would be required for each side of the circuit.

(25) (*a*) Waterproof sockets should be used.

(*b*) They should be connected and hung by separate rubber-covered stranded conductors, not smaller than No. 14 B. & S. The two conductors should preferably be twisted together when their length is over 3 feet. They should be soldered directly to the circuit wires, but supported so that the weight of the lamp socket and wires will not be borne by the circuit wires. Rosettes should not be used. See Art. **18.**

(26) (*a*) A single-pole switch may be used where it does not control over 660 watts.

(*b*) Because they cost less and the necessary wiring is cheaper. See Art. **36.**

(27) Because not more than 660 watts are allowed on one circuit by the Underwriters and No. 14 is plenty large enough to safely carry the current; moreover, the distances are usually so small that the drop is never too large on 110-volt or higher pressure systems, even with the maximum allowable number of lamps on the branch circuits. No. 14 wire being the smallest size allowed by the Underwriters is therefore used for most branch circuits. See Art. **32.**

INTERIOR WIRING.

(PART 3.)

---

(1) It is important to burn the lamps at a proper and uniform voltage, but the drop or efficiency is a secondary matter; hence, a large drop may be allowed and comparatively small wires may be used, but lamps of the proper voltage should be used even if this requires lamps of different voltages in the various parts of the circuit or system. See Art. **10.**

(2) See Art. **16.**

(3) It depends on the ratio of the number of turns in the primary and secondary coils of the transformer. See Art. **18.**

(4) Because a protective device for use on a constant-potential circuit is made to open the circuit in order to protect it, but on a constant-current system, it must *short-circuit* and *not open* the circuit. See Art. **23.**

(5) See Art. **23.**

(6) (*a*) A self-restoring annunciator is so constructed that when a button is pushed, its corresponding drop falls. The next call operates a magnet that moves a restoring device, which in turn resets the first drop.

(*b*) It obviates the necessity of restoring the drops by hand. Moreover, with hand-restored annunciators, there may be one or more drops down, due to their not having been promptly restored, and hence if another drop falls,

it may be difficult to tell which drop fell last and which one needs to be answered. See Art. **41.**

(7) Direct-current series-arc lighting systems. See Art. **17.**

(8) Since one side of the system is grounded, it is very easy for the current to start leaking to earth, and hence the fire risk is great, to say nothing of the risk from shocks. See Art. **29.**

(9) The wires must be rubber-covered and must be kept at least 8 inches apart. See Art. **24.**

(10) (*a*) A motor and starting resistance box must be protected by a cut-out and controlled by a switch that shows plainly whether it is on or off.

(*b*) Single-pole switches may be used with motors of $\frac{1}{4}$ horsepower or less and then only on low-tension circuits. See Art. **28.**

(11) It is dangerous to life and, moreover, a lightning discharge can easily start an arc, and an arc once started will persist even though the points between which it plays are separated several inches; hence, it is liable to start a fire. See Art. **17.**

(12) It should be surrounded by a wood platform supported on insulators and extended around the machine so that a man must stand upon the platform before he can touch any part of the machine.

(13) (*a*) Resistance boxes and reactive, or choke, coils.

(*b*) Resistance boxes may be used on direct- or alternating-current systems, but reactive, or choke, coils, although the more economical of the two, can only be used on alternating-current systems. See Art. **9.**

(14) No. See Art. **66.**

(15) See Art. **20.**

(16) It is best to use rubber-covered wire in very moist or wet places for bell and annunciator wiring. See Art. **42.**

(17) Their use is recommended and they must be used when required. See Art. **28.**

(18) Without special permission transformers must not be placed inside a building, except in central stations, and if a transformer is fastened to an outside wall, it must be separated from the wall by substantial supports. See Art. **19.**

(19) (*a*) The most common form of theater dimmer consists of a resistance split up into a number of sections, so that the amount of resistance between the terminals of the dimmer may be varied by the movement of a handle that controls a contact device.

(*b*) In series with the circuit, so that the total resistance, and hence the total current and intensity of illumination, may be varied as desired by manipulating the handle. See Art. **9.**

(20) Two wires should never be fastened under one unprotected or uninsulated metal staple and a staple should never be driven in so hard as to cut through or injure the insulation of the wire. See Art. **42.**

(21) See Art. **26.**

(22) Because all the air gaps at the burners in one circuit are in series, and hence offer a great resistance to the sparking current; and since a current will take the easiest path to ground, it follows that the current will jump to ground instead of across all the spark gaps if there is a point where the resistance to ground is less than the resistance of all the spark gaps. Consequently, it is very necessary to highly insulate the circuit on a series gas-lighting system in order to make the system work properly. See Art. **68.**

(23) Care must be taken to use a wire large enough to carry the current. The current required by the motor may usually be determined from the name plate, but if not given, the table, Art. **26,** may be used. Also, the motor must be equipped with a suitable starting box that complies with the Underwriters' requirements. See Art. **27.**

International Correspondence Schools

SCRANTON, PA.

Examination Questions for Diploma

FIRST EDITION

ELECTRIC LIGHTING

564A

INTERNATIONAL TEXTBOOK COMPANY
SCRANTON, PA.

Copyright, 1903, by International Textbook Company.

All rights reserved.

4209

Nr. 85

16

EXAMINATION PAPER

ELECTRIC LIGHTING

(1) What size of line wires should be used to transmit current for two thousand 16-candlepower, 60-watt lamps that are to be operated at a point 8,000 feet from the station? The E. M. F. at the transformer is 2,080 volts. The loss in the line is to be 10 per cent. of the power delivered. Allow 2 per cent. of the power delivered to the lamps for loss in the secondary ~~winding.~~ Transformer efficiency, 95 per cent.; single-phase current is to be used.

(2) When a voltmeter having a resistance of 18,000 ohms was connected across a certain circuit it indicated 115 volts. When connected between one line and the ground it indicated 10 volts. What was the insulation resistance of the other line wire?

(3) (*a*) What is meant by the power factor of a system? (*b*) How may the power factor of a circuit be determined?

(4) If a three-phase rotary converter is supplied with alternating current at 345 volts, what will be the E. M. F. at the commutator of the machine?

(5) The power factor of a 500-volt, three-phase induction motor is .85, and at full load the motor takes 25 horsepower from the line; what will be the full-load current in each line wire?

(6) Describe the action of the Stillwell regulator.

(7) How would you remedy the trouble due to an open circuit in one of the coils of an arc dynamo having a Gramme ring armature?

For notice of copyright, see page immediately following the title page

(8) What is the principle of operation of the Nernst incandescent lamp?

(9) In case the polarity of a series-arc machine should become reversed, how would you remedy the trouble and what precautions should be taken?

(10) A recording wattmeter reads 8,900 watt-hours at the beginning of the month and 25,000 at the end of the month. The constant of the meter is 2. If power is worth 5 cents per horsepower-hour, what should be the bill for the month?

(11) Describe the Bunsen photometer.

(12) Describe the Garton lightning arrester.

(13) What points should be taken into consideration in locating a central power station?

(14) Give a diagram of connections for transformers that have their primary coils connected across a three-phase system, and their secondary coils connected to an induction motor. Both primary and secondary to be △ connected.

(15) Suppose a coil of wire wound on an iron ring has a resistance of 5 ohms, an inductance of .5 henry, and the impressed E. M. F. is 100 volts alternating; frequency, 30 cycles per second; what current will flow through the coil?

(16) (*a*) How does capacity in a line affect the phase relation between E. M. F. and current? (*b*) If a line has self-induction, what device could be connected to it to partly neutralize the self-induction?

(17) Show by a sketch how you would connect up the primaries of two transformers to a single-phase circuit and have the secondary coils connected to three-wire distributing mains.

(18) (*a*) What is the principle of the action of a circuit-breaker? (*b*) What are the advantages of circuit-breakers over fuses?

(19) If a sixty-cycle alternator is connected to a circuit that has an inductance of .08 henry and a resistance of 15 ohms,

what E. M. F. must be supplied by the alternator to force a current of 15 amperes through the circuit?

? (20) What is a wattless current and how is it caused? Art. 48 Sec. 12

(21) (*a*) Why cannot shunt machines be run in parallel with compound-wound machines? (*b*) In case it were necessary to so operate them, what would you first do?

(22) (*a*) Make a diagram showing the general distribution of light from an open arc lamp. (*b*) The same for a direct-current enclosed arc lamp with opalescent inner and clear outer globes.

(23) If the open space between the sides of a coil on an alternator armature is much less than the width of a pole face, what will be the effect on the terminal E. M. F.?

(24) (*a*) Explain how you would locate a break on a series-arc light line by means of a magneto bell. (*b*) How would you use the bell to locate a ground?

(25) Describe the action of a balancing set as used in connection with a three-wire system.

(26) Describe the Wurts non-arcing lightning arrester.

(27) (*a*) What apparatus is usually placed on a single-phase generator panel switchboard? (*b*) Make a sketch and explain the connections for such a panel.

(28) Show how two-phase currents can be transformed to three-phase currents, describing the type of transformer used for this purpose.

(29) (*a*) Explain the difference between power and work. (*b*) What is the electrical unit of work? (*c*) What is the electrical unit of power?

(30) Six hundred 16-candlepower, 110-volt lamps are operated at a distance of $\frac{1}{4}$ mile from the station by means of the three-wire system. If the allowable drop on each side of the system is 5 volts, what size of wire should be used for the outside wires and the neutral, assuming that the neutral is made one-half the size of the outside wires?

(31) If a transformer is supplied with a primary E. M. F. of 1,000 volts and has 1,000 turns on the primary, how many turns must there be in the secondary to have an E. M. F. at the terminals of the secondary of 104 volts?

(32) (*a*) What are the essential features of an enclosed arc lamp as compared with the open arc lamp? (*b*) What are the chief advantages of the enclosed arc lamp?

(33) A Thomson recording wattmeter when tested made 15 revolutions of the disk in 1 minute and 30 seconds. If the constant of the meter were 2, what was the average number of watts expended in the circuit?

(34) One thousand kilowatts is to be delivered over a line
90 5 miles long (one way) to a load consisting of motors and lights;
14 three-phase, sixty-cycle system used; line loss to be 10 per cent. of the power delivered; E. M. F. at end of line, 10,000 volts. What size of wire should be used?

(35) Describe the C R regulator for use with the alternating constant-current series-system of electric lighting.

(36) Draw a diagram showing how you would connect up a recording wattmeter to measure the watts supplied to a group of lamps on the three-wire system.

(37) What is the difference between reactance and impedance?

(38) What must be done to one of a pair of compound-wound dynamos, which it is desired to run in multiple, when the drop in volts across the series-field of one machine at full load does not equal the drop in volts across the series-field of the other at full load?

(39) Why are platinum wires used for leading-in wires in an incandescent lamp?

(40) How would you locate a cross on two line wires of a circuit by means of the Varley loop test?

(41) Explain why only $\frac{5}{8}$ of the copper necessary for the two-wire system is necessary for the three-wire system.

(42) Show how a ground on a series-arc light line may be located by means of a voltmeter.

(43) (*a*) Describe a booster dynamo. (*b*) Why are boosters used in connection with lighting or railway work?

(44) How would you connect two synchronizing lamps? Draw sketch and explain how you can tell when two alternators are in synchronism.

(45) Describe the Stanley inductor alternator.

(46) If a certain object is 20 feet from a source of light, how many times will the illumination on it be reduced if it is removed to a distance of 60 feet?

(47) Describe the action of a ground detector suitable for a three-wire low-tension system. Illustrate by means of a sketch.

(48) What is the mean spherical candlepower of an incandescent lamp?

(49) Show by a sketch how one voltmeter may be connected so that it can be used to measure the E. M. F.'s of a number of dynamos.

(50) On what does the life of an incandescent lamp depend?

(51) Describe one type of constant-current transformer. Art. 4

(52) How is the regulation of the Brush multipolar arc dynamo accomplished?

(53) For what is the resistance, or choke, coil used in constant-potential arc lamps? Explain fully.

(54) (*a*) Why cannot constant-current series-arc lamps be regulated by a single coil in series with the arc, as in the case of constant-potential lamps? (*b*) How is the regulation of series-lamps effected?

(55) Explain the multi-circuit method of operating series-arc lamps, and point out its advantages. ~~art~~ Sec 19

Art. 33
Sec. 18

INDEX

NOTE.—All items in this index refer first to the section (see the Preface) and then to the page of the section. Thus, "Alternators 20 41" means that alternators will be found on page 41 of section 20.

S